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ASSESSMENT OF WASTEWATER MANAGEMENT, TREATMENT TECHNOLOGY, AND ASSOCIATED COSTS FOR ABATEMENT OF PCBs CONCENTRATIONS IN INDUSTRIAL EFFLUENTS. TASK II

Gayaneh Contos, et al

Versar, Incorporated

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All plants in the above categories have PCB discharges to either waterways or sewage treatment plants, under normal operating conditions. All plants have discharges to storm sewers or directly to waterways under heavy rainfall conditions.

Extensive survey of wastewater treatment technologies and cooperative laboratory work with several suppliers of treatment equipment and research facilities has confirmed that carbon adsorption technology is the best current candidate for successful removal of PCBs from the wastewaters. As an alternative UV-ozonation was considered. This technology is still in the research stage; however, it offers potential of complete destruction of PCBs all the way to CO_2, water and HCl.

Another adsorbent technology now in the development stage, AMBERLITE polymeric adsorbents, has demonstrated a PCBs removal efficiency roughly equivalent to carbon during laboratory tests. Further testing is needed with this adsorbent to accurately assess its potentiality.

For scrap oils and burnable solid wastes generated at these plants, high temperature, controlled incineration offers a straightforward method of destruction, whereas scientific landfilling appears to be the best suited mode of disposal for nonburnable contaminated solids.

Zero discharge objectives can be best achieved by eliminating discharge streams and developing recycle systems. All non-contact cooling water would be segregated, cooled, and recycled. All other wastewater streams would be pretreated. The portion of the pretreated water which would be used in the plant would be treated with carbon, while the excess water would be incinerated in a specially designed system which would allow for energy recovery.

Supporting data, rationale for the selection of above recommended treatment technologies and associated costs are contained in this report.

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PCBs water pollution	costs of treatment	
PCBs in land destined wastes		
PCBs incineration		
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Task II

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For

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Office of Toxic Substances
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February 3, 1976

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SECTION I

INTRODUCTION

1.0 OBJECTIVE OF THIS STUDY

The major objective of this study was to gather, evaluate and interpret specific kinds of information about industrial PCBs wastes in production of PCB and in electrical component manufacturing. The information was to provide the basis for establishment of enforceable PCBs effluent standards for industrial discharges. It was also to be useable in determinations concerning allowances for variances with pollution control regulations.

The specific need for the study was rooted in the conclusion of the adjudicatory hearing following publication of the proposed effluent standards by EPA on December 29, 1973. The conclusion at that time was that the proposed standards were based on inadequate data.

Thus there developed a high priority need for an assessment of wastewater management and treatment technology in these selected industries, the capital and operating costs to be borne in practice, the effluent concentrations and daily waste load of PCBs achievable, and the promise developing technology holds for future improvements in discharge and cost reductions.

2.0 SCOPE OF THIS STUDY

The overall scope was divided into three parts:

- Industry Characterization, to obtain the basic data and insights to be used in placing the following tasks in perspective.
- Investigations of Control and Treatment Technologies, to provide the technical bounds in establishing the allowable PCBs discharges, and give the rationale used in recommending technologies for practical current applications.
- Capital and Operating Costs for Selected Treatment Designs, to provide the economic factors for use in decisions involving cost and benefit analyses.

2.1 Industry Characterization

This portion was to completely describe, with the aid of flow sheets, the PCBs production method and the methods of manufacture of transformers and capacitors which contain PCBs. The intent was to cover every aspect of PCBs handling, storage, and loss as wastes in both production and manufacture. Data on quantities, character and concentrations of all discharges or losses to the environment were to be determined using available information provided by the plant personnel during on-site visits and by reasonable engineering extrapolations and estimates. Potential methods for reduction of discharges were to be noted, and costs already accumulated by the plants in reducing PCBs discharges were to be collected and interpreted.

2.2 Control and Treatment Technologies for PCBs Wastes

This portion of the study required assembly, examination to determine practicality and feasibility, and technical and economic evaluations of the subject methods. The subtask work statements suggest consideration of a wide variety of categories of methods for achieving PCB emissions reductions and elimination. These include manufacturing process and materials handling changes, use of substitute products, and novel methods of wastewater treatment that might be adapted from other industries or emerging technology. For consideration, a novel technique must show potential for PCBs waste treatment capabilities beyond that of current technology, at least in some respect. Improvements in current methods were to be fully considered. For selection as a prime or recommended treatment method, a candidate had to be amenable to capital and operating cost estimates for full scale, plant-sized treatment facilities at this time. Costs were to be applicable to a practical range of wastewater flows and levels of PCBs and other pollutants. Monitoring costs were to be included.

Treatment methods were to be examined and compared for effectiveness and reliability of achieving specified concentrations and absolute amounts of PCBs in ultimate wastewater disposal. Any transfer of PCBs to air, soil, or groundwater was to be determined for the treatment methods. The practicality of putting any treatment method into operation within one year and within three years of the promulgation of Section 307(a) effluent limitations was to be determined.

2.3 Capital and Operating Costs for Selected Treatment Technologies

This portion of the study was to assess the costs of each of the selected control technologies. Capital costs for both equipment and installation, annual operating costs for labor, materials, utilities, interest on invested capital, and other recurring costs were to be included. Costs were to be tied to preliminary design criteria which were to show capacities. Estimates of incremental costs per unit of increased production, or unit of PCBs handling, were to be made.

3.0 REPORT CONTENT

The report describes the three phase investigation by Versar Inc. into the practice and potential for control of PCBs emissions from PCB production and the manufacturing of capacitors and transformers containing PCBs. The first phase covers on-site plant inspections, industry and waste characterizations and details on practices currently in use. The second phase details an exhaustive search of present and potential treatment technologies applicable to PCB wastes. Included are selections and recommendations of the most practical approaches to control measures for installation within one year, and within three years, to achieve effluent limitations necessary to meet the purpose of Section 307(a), including zero discharge of wastewaters. Also included are selected technologies expected to contribute valuable approaches to the zero discharge potential for PCBs, but which are still in the research stages requiring more than five years for full development. The final phase presents the cost analyses of the recommended PCBs control technologies for wastewaters, scrap oils and solid wastes.

SECTION II

SUMMARY AND CONCLUSIONS

The table on the succeeding page gives a quantitative summary of daily PCB waste loads achievable by PCB manufacturer and the two major PCBs users (capacitor and transformer industries). This information was derived from data supplied by these industries and presents estimates of amounts of PCB wastes currently discharged by these industries to the environment via water, land and scrap oil generated and destroyed by these facilities via incineration.

The results of this study are grouped into three broad categories. First, those dealing with industrial characterization, production, use and emissions. The second group contains those giving an overview of available technologies for treatment of various PCB wastes and the third summarizes the costs associated with currently recommended waste treatment methods.

Industrial Characterization

1. The domestic annual production of PCBs in 1974 was 40,466,000 lbs of which approximately 22,000,000 lbs was used by capacitor manufacturers and 12,000,000 lbs was used by transformer industries. The balance reflects inventory changes and about 5,395,000 lbs of export sales.
2. There are a total of 37 PCB user (capacitor and transformer) plants in the U.S. and one PCBs manufacturer. Of the 38 plants, 10 discharge their effluents into the water ways while the remainder discharge PCBs into the sewage treatment plants. All plants in these categories have discharges under heavy rain fall conditions.
3. In addition to air emissions, there are three types of waste materials generated at these plants that require treatment and proper handling in order to minimize the PCB entry into the environment. These are:

TABLE 1

SUMMARY OF WASTE LOADS

	Daily Average		
	PCB Discharge in Waterways or Sewers	Land-Destined PCB Wastes	Scrap Oils to Incineration
PCB Manufacturer	3.06 lbs	301 lbs	1425 lbs
Capacitor Industries	5.86 lbs	4440 lbs	3968 lbs
Transformer Industries	0.17 lbs	Unknown	1750 lbs

(a) waste waters containing trace quantities of PCBs (10 to 500 ppb PCBs)

(b) waste PCBs, scrap oils and small quantities of process water highly contaminated with PCBs

(c) burnable and non-burnable solid materials contaminated with PCBs.

Quantitative estimates of these wastes are given in Table 1.

4. The quantities of land-destined wastes originating at the PCBs and capacitor manufacturing plants were estimated from sparse data supplied by a few plants. Similar information is not available from the transformer industry. These plants normally drum their solid wastes and have incomplete information on the number of drums accumulated annually. Some plants compact their wastes prior to drumming; others drum their wastes without the benefit of compacting. There are no adequate records to quantify these wastes. At some plants, the majority of this waste category, however, exists in an enormous total waste volume and probably at relatively low concentrations of PCBs. Further efforts are needed to adequately define these wastes.

5. As yet, very little is being done to control air emissions. The general assumption is that the vapor pressure of PCBs is so low that there will be essentially no air contamination. A few facilities, however, were reported to be filtering and chilling exhaust air from PCBs impregnation areas.

6. While the emissions of PCBs to water are expected to decrease due to improved pollution abatement of waterborne wastes, the release of PCBs to air and land is expected to increase. The primary source of increasing air emissions is the increase in the load of incineration materials due to proper handling of wastes which were previously discharged into the waterways or sewers. The quantities of land-destined wastes will also increase due to improved housekeeping measures.

7. Since most water used at these facilities is for non-contact cooling purposes, at most plants it is possible to significantly reduce the effluent volume by segregation of wastewaters, recycling and proper housekeeping measures.

8. Most plants have already undertaken PCBs containment programs in order to minimize the entry of PCBs into the environment.

9. There is no commercial scale wastewater treatment for PCBs removal being practiced beyond those of gravity settling of the heavy PCBs layers as a sludge from the bottom of sumps or tanks, and skimming of a contaminated oil-layer from the water surfaces.

10. Wastes in PCBs production and PCB wastes in capacitor and transformer manufacturing differ primarily in that the producer generates some higher boiling, highly chlorinated and polycyclic materials referred as "Montar" that are separated from the Aroclor products and incinerated. Thus the users of PCBs do not receive the higher boiling materials. Aroclor 1016 is the principal PCB used by capacitor industry; at some plants Aroclor 1242 and 1221 are also being used in limited quantities. Mineral oil is the principal coolant oil used by the transformer industry. PCB transformer oils (blends of 60 to 70 percent Aroclor 1254 or 1242 and 40 to 30 percent trichlorobenzene) are used in only 5-10 percent of these plants' manufacturing volume. However, it has been concluded that the characteristics of the waste materials and effluents generated in all these facilities are, in general, similar enough so that the same kinds of treatment technologies can be utilized for purposes of controlling PCB entry into the environment.

11. Most industrial analysis for PCBs in wastewaters are based on grab samples and probably have not been more accurate than about ± 50% at the one and ten ppb level.

12. Rivers receiving PCBs discharges for a number of years vary greatly in PCBs content with time, apparently depending upon PCB content in storm water runoff and the degree to which bottom sediment is agitated and suspended.

13. Wherever there have been PCB operations in the past, there are probably high concentrations in local waterways bottom sediments.

14. All water streams have greatly lowered PCBs contents:

    (a) when solids are removed
    (b) when dispersed or dissolved oils are removed
    (c) When the stream comes in contact with a wide variety of solid surfaces
    (d) when no surface active agents are present.

15. Over the past 45 years, waste PCBs from transformer and capacitor operations have been used as local road oiling compounds. Sometimes they were discarded in dumps adjacent to manufacturing facilities. These are sources of long term leaching of PCBs into waterways, particularly with storm water runoff.

Overview of Available Technologies for the Treatment of Various PCB Wastes

1. The most advanced treatment technology in use is incineration. The PCBs manufacturer and one user have plant scale incineration capable of destroying PCBs with very high efficiency. There are at least two commercial services (Rollins Environmental Services and Chemtrol Pollution Services) available, with four incinerator locations in the Eastern and Southern U.S., that destroy PCBs.

2. Incineration is primarily applicable to waste PCBs and scrap oils contaminated with PCBs. All installations have the capacity of "burning" some contaminated wastewater but, of course, the proportion of that water to the exothermic oil burning must be kept low.

3. Only one commercial incineration service (Rollins) can routinely handle all kinds of PCBs contaminated transformer and capacitor components, sludges, fuller's earth and other solids, as long as they can be contained in a 47 gallon fiber drum. One PCB user company incinerates transformer internals for purposes of metal recovery.

4. Adequate methodology is available for those plants wishing to control the release of PCBs to the environment. Currently available technologies can be applied to the efficient removal of PCBs from wastes, or their destruction with the other wastes.

5. The PCBs content of wastewaters can be lowered to the 1 ppb level or below by carbon adsorption, macroreticular polymer resins and probably other adsorbents.

6. Carbon adsorption is currently the best available technology for plant scale treatment of PCBs wastewaters. This conclusion is based on laboratory tests with PCBs in water, and on the long background of plant scale use of carbon adsorption for removal of organics from water.

7. UV-ozonation technology is the best demonstrated method, on the laboratory scale, for destruction of PCBs in wastewaters when the streams occur in large volume, on a relatively continuous flow basis and with PCBs at the ppb concentration levels. This technology has the potential for conversion of PCBs to CO_2, H_2O and HCl.

8. Waste liquid PCBs and scrap oils contaminated PCBs are best handled, as a guideline, by high temperature (2000-2400°F) and long residence time (2-3 seconds) incineration. However, because of incinerator design variables, the conditions should be chosen in each case to lead to 99.999% destruction.

9. Incinerators should be equipped with low temperature alarms, and low temperature shut down of PCBs feed. They should have high efficiency water scrubbers to prevent HCl dissemination.

10. The best incinerator combination for handling wastes from these industries is a rotary burner fired by a liquid burner, and followed by an afterburner and scrubber system. The rotary burner can be designed to handle a variety of solid materials, and the liquid burner can handle both the oily and water type wastes.

11. Polymeric resins (AMBERLITES) were found in laboratory tests to be approximately as effective as carbon in removing PCBs from water. Further pilot scale testing is needed with this newer (than carbon) technology to accurately assess its potential.

12. Although still in the laboratory stage, catalytic reduction of PCBs offers the possibility of reduction to biphenyl and HCl; and catalytic oxidation offers a potential for destruction of PCBs to CO_2, H_2O and HCl.

13. Reverse osmosis and ultrafiltration appear to offer a long term potential for a more maintenance-free, and lower operational cost method of separation of PCBs from water. Success is dependent upon specialized membrane development now being carried out at several facilities.

14. It is believed that treatment systems employing activated carbon and possibly UV-ozonation could produce effluents which would be at or below the limits of detectability for PCBs with currently available analytical techniques. However, since no full scale systems for the treatment of PCBs are in operation at this time, this possibility cannot be confirmed.

15. Unfortunately, no methodology is presently available which can guarantee "zero discharge" to the environment. "Zero discharge" objectives can be best met now by eliminating discharge streams and developing recycle systems. All streams that are high in pollutants and can't be treated for reuse and the rainwater runoffs should be collected and incinerated.

Costs Associated with Currently Recommended Waste Treatment Methods

1. The Table on the succeeding page summarizes the estimated maximum capital and annual costs for the treatment of wastes generated in each industry category. As shown
treatment of all contaminated and potentially contaminated wastewaters, the incineration of scrap oils and the incineration of contaminated solid waste generated in the domestic production and utilization of PCBs is $35.50 million and $9.61 million, respectively. The total annual cost given above represents $0.28 per pound of PCB utilized within the U.S., based on 1974 data.

2. Rainwater contribution to the capital and annual wastewater treatment costs was estimated at 15 and 25 percent, respectively. If significant isolation of the contaminated areas can be achieved these costs will be somewhat reduced.

3. The estimation of total maximum costs anticipated for the manufacturer and users of PCBs was facilitated by preparing cost estimates for each plant site visited during the course of this study and then aggregating to the total industry category on the basis of the percentage of the total industry represented by the visited plants.

4. The treatment system includes settling for solids removal, oil skimming, equalization, fine media filtration, terminal PCB treatment, flow measurement and sampling, and discharge to surface receiving waters. All sludges and free floating oils are disposed of through incineration. All backwash waters used in the system are recycled back to the gravity settling basin for treatment. All spent adsorbent is destroyed by incineration (for wastewater flows up to 300 gpm) or regenerated on-site for reuse (for waste flows above 300 gpm).

5. An activated carbon system was selected as the terminal PCB treatment method for purposes of estimating the maximum total costs. A potentially viable alternative to carbon adsorption, UV-ozonation, has less well defined capabilities. Additionally, it is believed that unless the UV-ozonation system can do an equal or better job of destroying PCBs at a lower cost, it will not be selected by these industries.

TABLE 2

MAXIMUM PCB INDUSTRY TREATMENT COSTS

Industry	Capital Cost	Total Annual Cost	Cost Per Pound Produced or Used
PCB Producer	$ 1,600,000	$ 595,000	$0.015
Capacitor Manufacturing	16,600,000	4,200,000	0.190
Transformer Manufacturing	17,300,000	4,815,000	0.401
Total	$35,500,000	$9,610,000	
Total Cost Per Pound of PCB utilized		$ 0.28	
Total Cost Per Pound of PCB discharged to waterways		$ 2896	

6. A carbon adsorption system will remove PCBs from industrial effluents to a level of one ppb or less. It is impractical to design an activated carbon system to obtain a choice of effluent concentrations. The operating cost savings for operations at various effluent PCB concentrations are expected to be too small to justify designing carbon adsorbers for PCBs removal at higher than one ppb level.

7. The work performed by Houston Research and Westgate Research on UV-ozonation indicates that the final concentration is a function of residence time, and that UV-ozonation systems can be designed to achieve any desired effluent PCB concentration.

8. Preliminary comparisons of the capital costs of the two systems show at least a 100 percent greater cost for the ozone system over the carbon. When pretreatment costs are combined with treatment, the UV-ozonation process is about 10 percent higher than the carbon process.

9. The design and fabrication of incineration equipment is a highly proprietary industry, it is believed that any attempt to estimate the cost of such systems on a rational basis would be fruitless. In addition, it seems quite improbable that the smaller PCB user plants would find it economically justifiable to install and operate such a system for destruction of scrap oils and solid wastes contaminated with PCBs. The alternative to on-site incineration is contract incineration. For purposes of cost estimation and based on the range of prices quoted by service companies, a flat rate of $0.10 per pound has been assumed for all scrap oil and solid wastes even if they are generated by facilities which have an on-site incinerator.

10. Contract incineration of large volume, dilute aqueous streams does not seem to be a feasible alternative due to the logistics and transportation cost. For purposes of achieving "zero discharge", capital costs for on-site incineration systems were developed. In this case, the accuracy of capital cost estimates are not deemed as critical in view of the high operating cost, primarily fuel cost, associated with this system.

11. The least cost "zero discharge" system comprises segregation of waters used in the plant and cooling and recycling all non-contact cooling water. All other wastewaters will be routed to a central system for equalization, settling and fine media filtration. The portion of the water to be utilized in the plant will be subjected to terminal treatment with carbons, the excess water will be subject to incineration in a specially designed system which would have the potential of energy recovery.

12. Capital and total annual costs to achieve "zero discharge", based on the system described above, was developed for selected plants. It was concluded that the total annual costs for "zero discharge" was about 2.0 to 12.0 times the cost of the carbon system (close loop cooling water case) when rainwater was included.

13. Rainwater runoff is a direct function of the locations' rainfall and runoff area. The rain runoff area may or may not be dictated by the size of the production facility. This single flow could provide the largest flow variation for all production facilities.

14. For the "zero discharge" system the rainwater contribution to the annual wastewater incineration cost is very high. Comparison of the two "zero discharge" cases ((1) inclusion of rainwater runoff as incinerating material and (2) exclusion of rainwater runoff) indicates the annual cost of the case 1 to be 2 to 42 times the cost of the case 2 for the various plants under study.

15. As a rough approximation, energy requirement for waste incineration is directly proportional to the hydraulic load of the unit. Water incineration is far more energy intensive than scrap oil incineration.

16. Energy requirement of each plant is proportional to the total hydraulic load of the pretreatment and terminal treatment systems.

SECTION III

RECOMMENDATIONS

There are indications within the PCBs manufacturer and PCBs user industries that progress is being made in air and water pollution abatement; however, little is being done to assure that the land-destined wastes are disposed of in an environmentally sound manner. This shortcoming can be attributed to higher costs associated with handling large volumes of wastes further information is needed regarding methods and costs of handling land-destined wastes.

Based on the summary and conclusions cited in Section II, the following recommendations are made:

1. Verification sampling should be conducted under controlled conditions in order to define the levels of PCBs discharged into the environment with higher degree of accuracy.
2. Promulgation and enforcement of regulations for water pollution abatement from stationary sources should be continued. Regulations for non-point sources should be initiated to minimize the entry of PCBs into the environment.
3. The use of more biodegradable PCB (Aroclor 1016) in transformer applications should be encouraged.
4. New regulations should be developed and enforced to ensure that the land-destined wastes from these facilities are disposed of in an environmentally sound manner.
5. Additional data should be developed to adequately characterize solid wastes generated by these three industries and then define methods and costs of handling these wastes.
6. The capability of various incineration facilities should be determined for PCBs destruction on a given doctored feedstock using a predeveloped and specific test plan. Analysis of available data indicated that there are differences of opinions as to optimum temperature level and residence time for PCB incineration.

7. Waste PCBs liquids and scrap oils contaminated with PCBs should be incinerated in approved facilities. New incineration facilities can be installed in one year.

8. Every effort should be made at each plant to minimize flows. The source of rain runoff contamination should be traced and efforts should be directed to isolate the contaminated areas.

9. Disposable foot coverings and outer garments should be provided at each plant; work clothing should not be allowed to leave the plant other than via solid waste.

10. All spills should be cleaned via rags or floor dry and disposed of in waste drums for incineration. All solid waste should be disposed of in impervious sealed containers.

11. As a housekeeping measure, all sinks in the PCB impregnation and PCBs handling areas should be contained. The wash water from these sinks should be properly treated prior to disposal.

12. Wastewaters containing PCBs should be treated by the standard sanitary procedures of settling the sludges and sediments, removal of suspended solids, and skimming to remove floating oils; all prior to specialized terminal treatment for PCBs.

13. Wastewater pretreated as recommended above should then be treated in carbon adsorption columns for removal of PCBs to the ppb levels or less.

14. Spent carbon should be regenerated in an environmentally sound manner, or sent to approved incineration along with other PCBs wastes.

15. Waste capacitor and transformer components, absorbent solids, adsorbents, soil, cloth, paper, wood and similar solids contaminated by PCBs should be incinerated in a rotary kiln. The exhaust should be fed to an incineration unit for liquid PCBs, equipped with afterburner and scrubber to assure destruction of all PCB vapors. Such facilities can be installed in one year.

16. Exhaust air from PCB impregnation areas should be filtered through absorbent carbon, with chilling, if necessary, to meet clean air quality standards. This equipment can be installed in one yaar.

17. Research on the catalytic oxidation of dilute PCB vapors in air streams should be conducted to determine the feasibility of low temperature destruction of PCBs by an energy saving process. This method will take more than three years to develop.

18. Research on UV-ozonation should be continued to achieve the following goals:

    a) determination of optimum conditions for a continuous flow reactor system using actual wastewaters
    b) conduct on-site demonstration tests using portable equipment at a PCB using plant, operating on a wastewater slipstream
    c) design, construct and operate a pilot unit, on actual wastewater, to develop reliable capital and operating cost

    UV-ozonization treatment technology can be fully developed and installed in three years.

19. Pilot scale R&D on reductive dechlorination should be continued to obtain reliable capital and operating costs. This method will probably be available for plant scale application in three years time.

20. Laboratory research on catalytic oxidation as a method of PCBs destruction should be initiated. The feasibility of wet catalytic oxidation using suspended commercial catalysts at elevated temperatures (200°-500°C) and elevated pressures (500 to 1000 psi) should be determined. This method will take more than five years to develop.

SECTION IV

WATER USE AND WASTE CHARACTERIZATION

1.0 INTRODUCTION

This section discusses specific water uses in the manufacture of Polychlorinated Biphenyls (PCBs) and by selected users of PCBs. The process wastes are characterized as raw waste loads emanating from specific operations in the manufacturing of these products, and, where known and reported, they are given in pounds per ton of PCB used. The specific water uses and amounts are given in terms of gallons per day for each of the facilities contacted or visited in connection with this study. Where appropriate, the raw wastes in the effluents are given both in terms of concentration, mg/liter, or in terms of pounds per day discharged.

2.0 SPECIFIC WATER USES

Water used in these industries fall into four major characterization headings. The principal water uses are:

(1) Non-Contact cooling water

(2) Process Water -
  (a) water used in detergent washing of capacitor components or PCB filled capacitor exteriors.
  (b) water used in scrubbers for air pollution control
  (c) water used as vacuum pump seal
  (d) condensate from steam jet ejectors used at some plants to achieve vacuum
  (e) phosphatizing and fluoride baths used to prepare the metal surfaces for painting
  (f) water used in paint booths for scrubbing purposes

(3) Auxiliary processes water

(4) Miscellaneous water

Non-contact cooling water is defined as that cooling water which does not come into direct contact with any raw material, intermediate product, by-product or product used in or resulting from the process. The largest use of non-contact cooling water in these industries is for the cooling of equipment such as vacuum pumps, tanks and air compressors. At many plants the non-contact cooling water is also contaminated with PCBs as the general practice is to discharge these streams combined with process waters or to discharge them through troughs or trenches that were previously contaminated with PCBs.

Process water is defined as that water which, during the manufacturing process, comes into direct contact with any raw material, intermediate product, or by-product used in or resulting from the process.

Auxiliary process water is defined as that used for processes necessary for the manufacturing of a product but not contacting the process materials; for example, blowdowns from cooling towers and boiler blowdowns. The volume of water used for such purposes in these industries is minimal. However, when they are present, they usually contain PCBs.

Miscellaneous water uses vary among facilities with general usage for showers, hygiene, eye wash stations, laundry water and sanitary uses. This water also contains PCBs.

3.0 INDUSTRY AND PROCESS WASTE CHARACTERIZATION

For the manufacture of PCBs and each PCB user manufacturing operation the following information is given:

- Name and the location of companies in each category;
- A description of the processes at the facilities studied and pertinent flow diagrams, where appropriate
- Raw waste load data per ton of PCB used and sources of these wastes;
- Water usage data in terms of gallons per day

- Treatment and housekeeping measures practiced at the facilities and on-going PCB containment programs
- Plant waste effluents found and their composition

3.1 Manufacturing Process - Polychlorinated Biphenyls (PCBs)

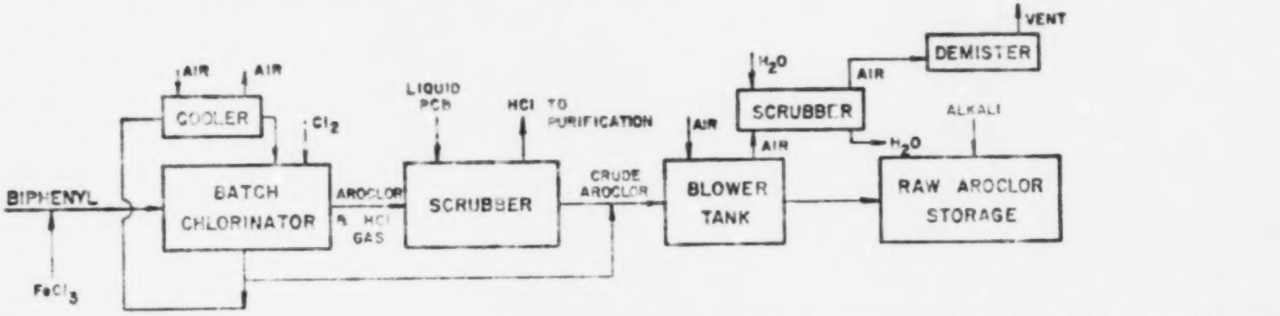
3.1.1 Process Description

Monsanto, the sole domestic manufacturer of PCBs, manufactures this chemical in their Sauget, Illinois plant. The basic raw material is biphenyl which is manufactured from pure benzene in another Monsanto plant. The PCB manufacturing operation is conducted in two steps. First, biphenyl is chlorinated with anhydrous chlorine in presence of ferric chloride to produce crude PCBs and then the crude PCBs are distilled to obtain the finished product. A schematic flow diagram of this process is given in Figure 3.1.1-1.

The reaction section consists of 6 reactors (3 batch and 3 cascade). Currently Monsanto manufactures four different types of Aroclors (1242, 1016, 1254 and 1221). For the manufacture of any given product, the chlorinator is charged with proper quantities of biphenyl and catalyst and heated beyond the melting point of biphenyl. The flow of vaporized chlorine is then started and the charge is circulated with a pump. Throughout the chlorination, the temperature is kept above the melting point of the mixture, but below 150°C to avoid excessive sublimation and plugging of the line discharging the hydrogen chloride produced by the chlorination. The reaction pressure is maintained near atmospheric. The degree of chlorination is principally determined by the time of contact with anhydrous chlorine. The contact time varies from 12 to 36 hours for the manufacture of different Aroclor types. The degree of chlorination is measured by the specific gravity of mixture or the ball and ring softening point when the product is viscous.

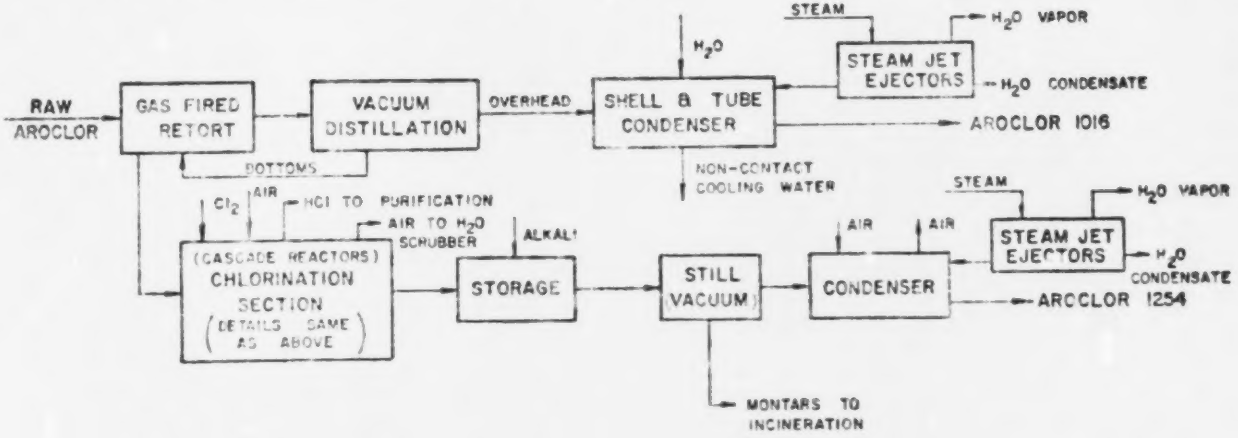
The vapors from the chlorinator (HCl containing PCBs) are scrubbed with liquid Aroclor and the gaseous HCl is sent to another plant at the Sauget complex for purification. The crude product is held at an elevated temperature and blown with dry air for several hours, after which it is sent to the raw Aroclor storage tank where a few tenths of 1 percent of alkali is stirred

Figure 3.1.1-1A-PREPARATION OF CRUDE CHLORINATED BIPHENYLS-MONSANTO KRUMMRICH PLANT



BIPHENYL
$FeCl_3$
AIR
AIR
COOLER
Cl_2
BATCH CHLORINATOR
AROCLOR & HCl GAS
LIQUID PCB
HCl TO PURIFICATION
SCRUBBER
CRUDE AROCLOR
AIR
BLOWER TANK
AIR
H_2O
SCRUBBER
AIR
DEMISTER
VENT
H_2O
ALKALI
RAW AROCLOR STORAGE

Figure 3.1.1-1B-DISTILLATION OF CRUDE PRODUCTS-MONSANTO KRUMMRICH PLANT



RAW AROCLOR
GAS FIRED RETORT
VACUUM DISTILLATION
BOTTOMS
OVERHEAD
H_2O
SHELL & TUBE CONDENSER
NON-CONTACT COOLING WATER
STEAM
STEAM JET EJECTORS
H_2O VAPOR
H_2O CONDENSATE
AROCLOR 1016
Cl_2
AIR
HCl TO PURIFICATION
AIR TO H_2O SCRUBBER
(CASCADE REACTORS) CHLORINATION SECTION (DETAILS SAME AS ABOVE)
ALKALI
STORAGE
STILL VACUUM
MONTARS TO INCINERATION
AIR
AIR
CONDENSER
STEAM
STEAM JET EJECTORS
H_2O VAPOR
H_2O CONDENSATE
AROCLOR 1254

with the material to react with any remaining hydrogen chloride or ferric chloride. The air from the blower tank is scrubbed with water and vented to the atmosphere through a demister.

The raw Aroclor is subsequently batch distilled under reduced pressure to remove the color, and the traces of hydrogen chloride and ferric chloride. The methods of purification are different for the different types of end products. Raw Aroclor 1254, 1242 and 1221, each are distilled in stills under reduced pressure, achieved via steam jet ejectors; the condensate from the still is the finished product while the bottoms are the Montars which are drummed and sent to incineration.

The distillation section for the 1016 product consists of a gas fired retort and a vacuum distillation tower. The latter is used to allow the separation of the higher chlorinated, less biodegradable compounds from the relatively lower chlorinated and more biodegradable ones. The raw Aroclor (42% chlorinated material) is fed into the reboiler. The vacuum in the tower is maintained at about 100 mg Hg via steam jet ejectors. The steam is partially condensed and the condensate is discharged into the plant discharge sump. The first cut from this tower is recycled back to the retort. At a preset overhead temperature the 1016 product is collected and sent to the product storage. The high boiling residue from the tower is sent to a subsequent chlorination cycle and the resulting raw Aroclor is distilled in a still. The overhead from this still is the finished product. The bottoms from this tower are the Montars, which are sent to incineration.

For special orders, in order to increase electrical resistivity, the Aroclors are stirred, at an elevated temperature, with a few tenths of 1% of well-dried fuller's earth and then filtered through paper.

All Aroclors are stored at 150°F. Steam coils are used on the storage tanks for heating these tanks.

3.1.1.1 PCB Production and Usage

The William G. Krummrich plant at the Sauget complex has an annual design capacity of 48 million pounds chlorobiphenyls. Table 3.1.1.1-1

TABLE 3.1.1.1-1 PCB MANUFACTURE & SALES

	(Thousands of pounds)	
	1974	First Quarter 1975
U.S. production	40,466	8,532
Domestic sales	34,406	7,986
U.S. export sales	5,395	1,538
Domestic Sales by PCB Grade		
Aroclor 1221	57	10
Aroclor 1242	6,207	2,201
Aroclor 1254	6,185	2,115
Aroclor 1016	21,955	3,660

Predominant Utilization of Aroclors

Aroclor 1221 & 1016	Capacitor applications
Aroclor 1242 & 1254	Transformer applications

present data from Monsanto related to production and sales on PCBs for the year 1974 and the First Quarter of 1975. Table 3.1.1.1-2 presents approximate molecular composition of these Aroclors as published by Hutzinger et al (O. Hutzinger, S. Safe and V. Zitko, "Chemistry of PCBs", CRC Press, 1974).

The majority of the PCBs produced in this plant is marketed domestically. At present, almost all Monsanto's PCB production is being used in "closed electric systems" (transformer and capacitor applications).

3.1.2 Raw Wastes

The raw wastes from the manufacturing area consist of the liquor from the scrubber, the condensate from the steam jet ejectors, water used for showers and eye baths, miscellaneous floor wash downs, waste oil collected in drip pans and drums, and montars which are the bottom cut from their stills. The composition and the quantities of the individual waste stream are not monitored. All effluent streams generated in the manufacturing area are directed into the sumps in this area. The waste oil collected in the drip pans and the montars are emptied into 55 gallon drums and sent to incineration.

The raw wastes generated in the incinerator consist of the venturi scrubber liquor and the water phase from the separator sump in the incinerator area. The composition of the combined stream is monitored. However, the composition of the individual streams is not known. Non-product PCB discharges are shown in Figure 3.1.2-1. It has been estimated that this plant generates about 25 lbs. of scrap oil and Montar per ton of PCB produced. Additionally the quantities of material sent to landfill approximates to 5.4 lbs. per ton of PCB produced. Additionally, reports that the plant's PCB contribution to air is under 1 lbs/day.

3.1.3 Plant Water Usage

On the average, the PCB plant uses a maximum of 388,800 gallons of water and a maximum of 360,000 lbs. of steam, daily. Water is used for non-contact cooling purposes in shell and tube condensers, in a water scrubber, for floor washings, for showers and in eye baths. Steam is used in the steam jet

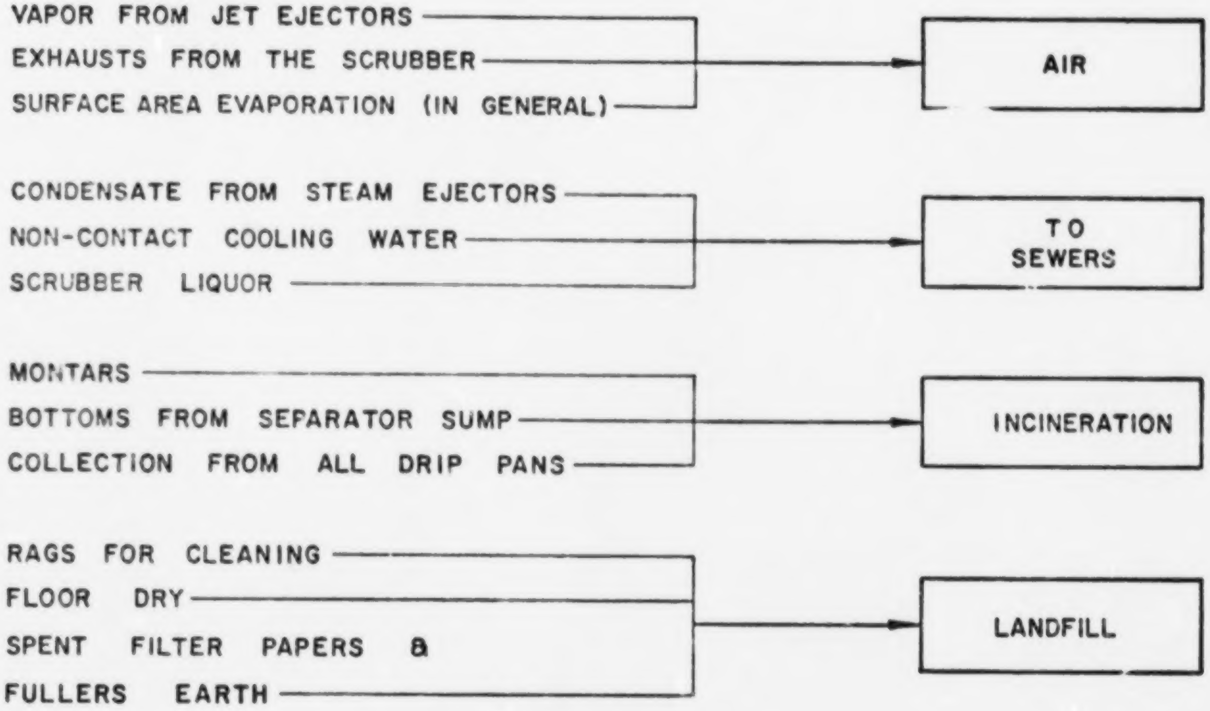
TABLE 3.1.1.1-2

APPROXIMATE MOLECULAR COMPOSITION OF AROCLORS

	Aroclor Type or Grade (percent composition)			
Chlorobiphenyl	1221	1242	1254	1016
$C_{12}H_{10}$	11	<0.1	<0.1	<0.1
$C_{12}H_9Cl$	51	1	<0.1	1
$C_{12}H_8Cl_2$	32	16	0.5	20
$C_{12}H_7Cl_3$	4	49	1	57
$C_{12}H_6Cl_4$	2	25	21	21
$C_{12}H_5Cl_5$	0.5	8	48	1
$C_{12}H_4Cl_6$	ND	1	23	<0.1
$C_{12}H_3Cl_7$	ND	<0.1	6	ND
$C_{12}H_2Cl_8$	ND	ND	ND	ND
$C_{12}H_1Cl_9$	ND	ND	ND	ND
$C_{12}Cl_{10}$	ND	ND	ND	ND

*ND - Denotes non-detectable

Figure 3.1.2-1- NON-PRODUCT PCB DISCHARGES AT MONSANTO'S KRUMMRICH PLANT


VAPOR FROM JET EJECTORS
EXHAUSTS FROM THE SCRUBBER
SURFACE AREA EVAPORATION (IN GENERAL)
AIR
CONDENSATE FROM STEAM EJECTORS
NON-CONTACT COOLING WATER
SCRUBBER LIQUOR
TO SEWERS
MONTARS
BOTTOMS FROM SEPARATOR SUMP
COLLECTION FROM ALL DRIP PANS
INCINERATION
RAGS FOR CLEANING
FLOOR DRY
SPENT FILTER PAPERS &
FULLERS EARTH
LANDFILL

ejectors and for steam tracing purposes. The plant uses municipal water and purchased steam.

The process water from this facility consists of the liquor from their scrubber and the steam condensates which are discharged in one of the two sumps in the manufacturing area.

Additionally, 273,600 gallons of water are used in the incinerator daily for quenching the hot gases from the fire box. The resulting weak muriatic acid in the quench pot is used in the venturi scrubber and in the packed tower.

The type and quantities of water used and discharged at this plant are summarized below.

Water Balance

- Manufacturing Plant

	Quantities, GPD	
	Used	Discharged
Process Water		
in water scrubber	14,400	14,400
misc. floor wash downs	7,200	7,200
condensate from steam jet ejectors	—	14,400
Non contact cooling water	360,000	360,000
showers, eye bath	7,200	7,200
condensate from steam tracers	--	28,800
Total	388,800	432,000

- Incinerator

	Used	Discharged
water used for hot gas quenching	273,600	273,600
water phase from the sump	--	14,400
Total	273,600	288,000

3.1.4 Wastewater Treatment and Housekeeping

Monsanto reports significant environmental controls at their Krummrich, Sauget plant. Since 1969, they have invested more than 22 man-years of work and millions of dollars in this program. The in-house goals have reduced the PCB discharges into water to about three pounds per day.

A John Zink designed incinerator was erected at Sauget in 197. to safely dispose of PCBs. A schematic flow diagram of this operation is given in Figure 3.1.4-1. Aroclor is steam atomized and fed into the fire box. Natural gas is used for combustion and the feed is incinerated at temperature above 2200°F at 5 percent excess oxygen with a retention time of 2-3 seconds. The gases are quenched with water and the exhausts from the quench pot are passed through a high-energy venturi scrubber, then through a packed column which is irrigated by the weak muriatic acid originating from the quench pot. Exhausts are then vented to atmosphere through a demister. These exhausts as well as the effluent from the incinerator section are monitored.

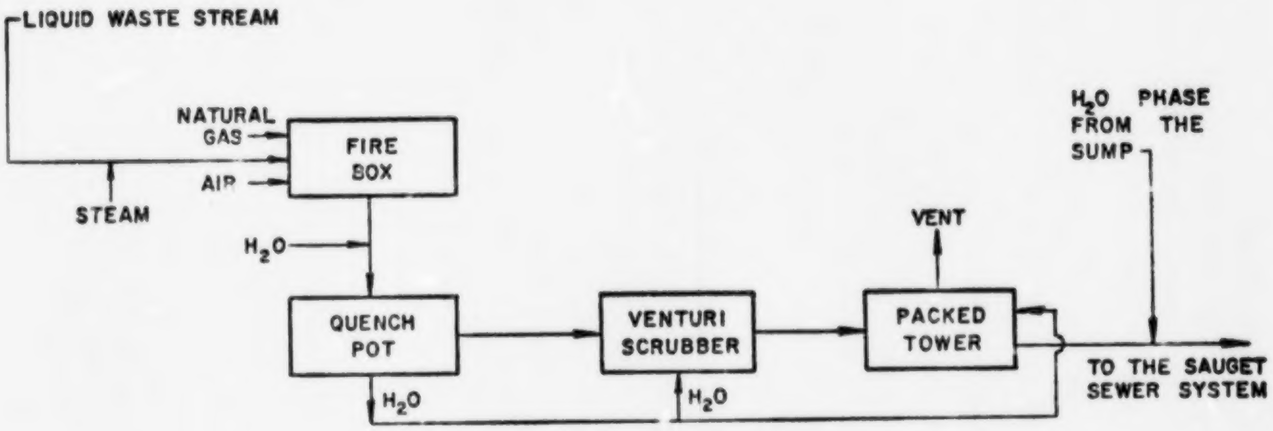
In the incineration area, drainage is directed to trenches and piping which flow into a 10,000 gallon underground concrete basin. The water layer from this basin is pumped continuously, combined with the scrubber liquor, metered, monitored and discharged into the sanitary sewers of the Sauget complex and from there it is sent to the East St. Louis municipal sewers. The organic phase from the sump is periodically pumped into waste storage tanks for incineration.

The incineration unit has a rated design capacity of 10 million pounds per year. However, since the start of its operation this unit has achieved a service factor of about 0.60. Monsanto reports that this incinerator can achieve a maximum of 6 million pounds of capacity annually; the unit is plagued with various mechanical problems.

Monsanto uses their incinerator to process both their own wastes and as a service to other industries. The service charge for incineration is an average of 5¢ per lb. of material, but the cost appears to be increasing.

The incinerator feed is brought into the plant either by truck in 55 gallon sealed drums, by tank trucks or by rail. The drums are opened, picked up by a fork lift and emptied into a concrete pit. The tank truck carrying the waste liquids enters the incinerator area and the liquid waste is then pumped from the truck into the pit. The material in this pit is periodically pumped via a vertical certrifugal pump in one or the four 20,000 gallon, each, incinerator waste feed tanks.

Figure 3.1.4-1-PROCESS FLOW DIAGRAM OF THE JOHN ZINK INCINERATOR AT MONSANTO'S KRUMMRICH PLANT


LIQUID WASTE STREAM
NATURAL GAS
AIR
STEAM
FIRE BOX
H_2O
QUENCH POT
H_2O
VENTURI SCRUBBER
H_2O
VENT
PACKED TOWER
H_2O PHASE FROM THE SUMP
TO THE SAUGET SEWER SYSTEM

The rail car is brought into a designated area close to the incinerator site. The material from the rail car is normally pumped into a long term, 500,000 gallon storage tank. The material from this tank is pumped into the incinerator feed tanks located on the incinerator pad, when required.

Drainage is provided along the rail tracks. These drains empty into the 10,000 gallon sump located under the incinerator pad.

In the manufacturing area, Monsanto has taken a number of significant steps to prevent loss of PCBs to the environment. Drainage is directed to trenches and piping, and then to one of two concrete 3,000-gallon underground settling basins. This insures PCB containment in case of accidental spill or equipment failure. Relief valve lines and atmospheric vents are routed through catch tanks, or are redirected to settling basins.

When small quantities of PCBs are collected in the settling basins of the manufacturing area they are later pumped into 55 gallon drums, and eventually incinerated. The overflow from these sumps is combined with the non-contact cooling water used at the plant, monitored and then discharged into the Sauget complex's sanitary sewer and from there to the East St. Louis municipal system.

PCBs are packed and shipped in galvanized-steel 55 gallon drums, or in railroad tank cars. All tank cars are top loaded. In the drum filling area spills are cleaned via rags or floor dry and these materials are drummed and sent to landfill located in the town of Sauget.

In the PCB truck or rail car loading area drainage is directed into a small concrete pit. The material accumulated in this pit is periodically pumped into the basins located in the manufacturing area.

Nitrogen blanketing is provided on storage tanks to eliminate any "breathing" of the tanks and resultant PCB escape.

Mist eliminators have been installed in vapor lines to eliminate the possibility of PCBs leaving the manufacturing area through these lines.

Finally, underground sewers have been replaced with aboveground sewers, and repaired or combined with others, so that the effluent from the department can be monitored. In addition, this step will prevent any unknown buildup of PCBs in the sewer systems or any contamination of PCBs into other sewers.

A high housekeeping level is maintained in the plant itself. Housekeeping responsibilities which the operators have assumed are as follows:

- All pumps are checked for leakage on every shift. Drip pans that collect leaks are emptied into scrap PCB drums.
- All leaks are reported and documented so that corrections can be made and settling basins observed.
- "Floor Dry" is used to absorb any PCBs that have spilled or leaked. If it becomes necessary to flush PCBs to the settling basin, a minimum amount of water is used.
- Sampling drums and scrap PCB drums are quickly palletized, labelled and transferred to the incineration area.

3.1.4.1 Treatment Facility for the Effluent from Sauget Complex

The processing and incineration departments' aqueous effluent enters the plant sewer system, and this system discharges into the Sauget Village waste sewer system. The combined streams then flow to the village primary treatment plant. The village treatment plant is under expansion to a secondary chemical treatment plant, scheduled for 1976 completion.

Additionally, evaluations are being conducted to include the village plant discharge in a projected regional biological treatment plant.

3.1.5 Plant Effluents

This plant has no point source discharge from their operation. There is a single discharge from the manufacturing operation (the combined stream of process and non-contact cooling water) to the main sewer system of the Sauget complex and there is a second discharge from the incinerator area to the same sewer system. The composition of these streams as reported by Monsanto are as follows:

	Effluent from the Manufacturing Operation	Effluent from the Incineration area
flow rate, gpd	432,000	288,000
PCBs, ppm	0.75	0.15
PCBs, lbs/day	2.70	0.36

It has been reported that these effluents are clear liquids with essentially no suspended solids. The incinerator effluent may contain some amounts of chloride. However, no information is available on the chloride content.

3.2 Askarel Capacitor Manufacturing Industry

Presently 90-95 percent of all capacitors manufactured in the U.S. are of the PCB impregnated type. Two important types of capacitors are phase correctors on power lines and ballast capacitors for fluorescent lighting. Aroclor 1016 is the principal PCB used in this application; at some plants Aroclor 1242 and 1221 are also being used in limited quantities. The principal types of Aroclor impregnated capacitors and their applications are given below.

A. High Voltage Power

Generally AC capacitors are used to improve the power factor of a circuit. Power factor is the ratio of true power in watts to the apparent power as obtained by multiplying the current flowing to the load by the circuit voltage. The power factor correction can be made directly at the load or at utility substations. In the latter case high voltage units will be designed for 4,800 to 13,800 volt service. To the utility engineer the use of capacitors is purely a matter of economics. The main benefits that result from the use of capacitors are:

1. Reduction of losses associated with the delivery of electrical power to the point of use.

2. Reduction of the investment required in equipment for delivering electrical power to the point of use, which may be broken down into:

   a. Reduction of line current for the same kilowatt load.

   b. Reduction of the kva rating of equipment required to handle the same kilowatt load.

   c. Reduction of the transmission line voltage drop for a given kilowatt load.

   d. Control of delivered voltage if the capacitor kva is varied.

Electric utilities also use capacitor banks in series with distribution circuits to improve voltage regulation.

B. Low Voltage Power

Capacitors installed in industrial plants at the demand site (typically large motors and welders) are designed for 230 to 575-volt service. Capacitors installed near the loads are the most efficient way to supply the magnetizing current to produce the flux necessary for the operation of inductive devices. Rates for the sale of power are generally structured to encourage power factor correction at the site, eliminating the need for the electric utility to transmit both power-producing current and magnetizing current all the way from the generator to the plant site.

The same considerations apply to induction heating applications, the principal difference being that capacitors for this application are designed for operation at 960 to 9600 Hz.

C. Lighting

Capacitors improve the efficiency of lighting systems. A fluorescent or mercury vapor lamp can be ballasted without the use of a capacitor, but the power factor of the lighting system would then be in the range of 50 to 60%. For commercial or industrial lighting with either fluorescent or high intensity discharge lamps, the use of a capacitor in the circuit provides part of the lamp ballasting and brings system power factor into the range of 90 to 95%.

D. Air Conditioning

As in the lighting applications, the capacitor improves system efficiency. Air conditioners could be made to operate without capacitors, as do home refrigerators, but because of the higher capacity required for air conditioners, the resultant line current would virtually eliminate home "plug-ins" and would still further overburden a seriously threatened national power network. Almost all air conditioner pump motors are of the split-winding type on which the capacitor provides phase differential for the so-called start winding, thus delivering good starting torque. The proper size capacitor permits high (90%) power factor after start-up.

E. Industrial Electronics

This market category is a catchall covering many varied applications, two important ones being motor run and power supply applications. Motor run applications are for pumps, fans, and farm feed equipment, and do not differ significantly from air conditioning applications. The power supply market uses capacitors principally to provide high power factor, but through careful design the capacitor can also provide wave shaping where desired.

3.2.1 Askarel Capacitor Manufacturing Plants

There are seventeen companies in the U.S. which manufacture askarel capacitors at nineteen plants. The name and the location of these plants are given in Table 3.2.1-1. Some plants manufacture industrial capacitors only and others manufacture power capacitors.

Ten major companies were contacted. Detailed information was obtained on six plants. Four plants were visited. The data herein represents approximately 50 percent of 1974 PCB usage in capacitor application. The PCB usage in this category was approximately 22,000,000 lbs. in 1974. The PCB usage in individual plants is considered by these companies to be confidential information. The range of PCB usage at these plants was 64,000 fold in 1974. Plant ages range from five to thirty-seven years.

Capacitors used in lighting and air conditioning applications contain 0.05 to 1.0 lbs. of Aroclor. The largest power capacitors contain about

Table 3.2.1-1

U.S. Capacitor Manufacturing Industry Using PCBs

Company Name (In order of PCBs Usage)	Location of the Plant
General Electric Company	Hudson Falls, N.Y. Ft. Edward, N.Y.
Westinghouse Electric Corp.	Bloomington, Ind.
Aerovox	New Bedford, Mass.
Universal Manufacturing Corp.	Bridgeport, Conn. Totowa, N.J.
Cornell Dubilier	New Bedford, Mass.
P.R. Mallory & Co., Inc.	Waynesboro, Tenn.
Sangamo Electric Co.	Pickens, S.Carolina
Sprague Electric Co.	North Adams, Mass.
Electric Utility Co.	LaSalle, Ill.
Capacitor Specialists Inc.	Escondido, Calif.
JARD Corp.	Bennington, Vt.
York Electronics	Brooklyn, N.Y.
McGraw-Edison	Greenwood, S. Carolina
RF Interonics	Bayshore, L.I., N.Y.
Axel Electronic, Inc.	Jamaica, N.Y.
Tobe Deutschmann Labs.	Canton, Mass.
Cine-Chrome Lab, Inc.	Palo Alto, Calif.

77 lbs. of Aroclor. The most popular size contains 36 lbs. Capacitors are not rebuilt and returned to service after failure. They are disposed of and replaced by new units. G.E. reports that high voltage utility capacitors, low voltage power capacitors, and induction heating capacitors are manufactured at a rate of 200,000 per year, about 2 to 3% of which are replacements; the balance are for new installations. The current market for capacitors used in lighting applications is about 44,000,000 units annually of which 10% are estimated to be replacement ballasts. The current market for capacitors in air conditioning application is above 12,000,000 units annually, with 5% of these estimated to be for replacement usage. The market for capacitors in industrial electronics applications is estimated at 23,000,000 units per year with no estimate as to the relative size of the replacement market.

3.2.1.1 Askarel Handling

In most plants PCBs are shipped via tank car to a rail siding several miles from these plants. Individual plants provide a designated tank truck for the transfer of the PCBs from the rail yard to the manufacturing plant. To large plants, PCBs are brought via rail cars into the plant site

In most plants PCBs are unloaded and transferred to the PCB storage tank without the benefits of any curbs or dikes. At very few plants, the unloading operation of the PCBs from the tank car to the storage facility is confined and the receiving area is roofed and diked.

PCBs from the raw storage PCB tanks are filtered through fuller's earth and stored in finished product storage tanks. PCBs are next pumped from the storage tanks to the impregantion areas for use. Excess PCBs from these areas are recycled back to a designated tank and from there either filtered and reused or, if defective, it is pumped into the scrap storage tank.

Spent fuller's earth employed at these plants is either drummed and stored at the plant site or is sent to a landfill.

3.2.1.2 Process Description

Most plants in this category manufacture either large power capacitors or small (including less than 2 lbs. of PCBs) industrial type units. The large capacitors are either flood filled or manifold filled. All small capacitors are flood filled either in a vacuum tank or in an automatic "carousel" arrangement where loading and unloading occurs at one station, and the capacitors in each cell are progressively dried, evacuated and filled.

A generalized schematic flow diagram for the manufacture of large capacitors and small industrial capacitors are given in Figures 3.2.1.2-1 and 3.2.1.2-2, respectively. The basic manufacturing operation at these plants can be divided into two major operations.

a) Non PCB related operations consist of the following steps:

- Fabrication of capacitor cans, covers and brackets from sheet aluminum or steel. Smaller plants, however, purchase capacitor casings, capacitor terminals, connectors and foil.
- Vapor degreasing or detergent washing of metal components. At some plants, ultrasonic cleaning is used to clean smaller components.
- Roll winding the capacitor paper or polypropylene film with aluminum foil.
- Complete assembly of capacitor components and sealing with covers. In some units fill holes are provided for PCB introduction; in others PCBs are introduced through bushings or a valve.
- Leak testing via mass spectrometer and pressure testing prior to vacuum drying.

b) PCB related operations

Three completely different impregnating techniques are employed by this industry.

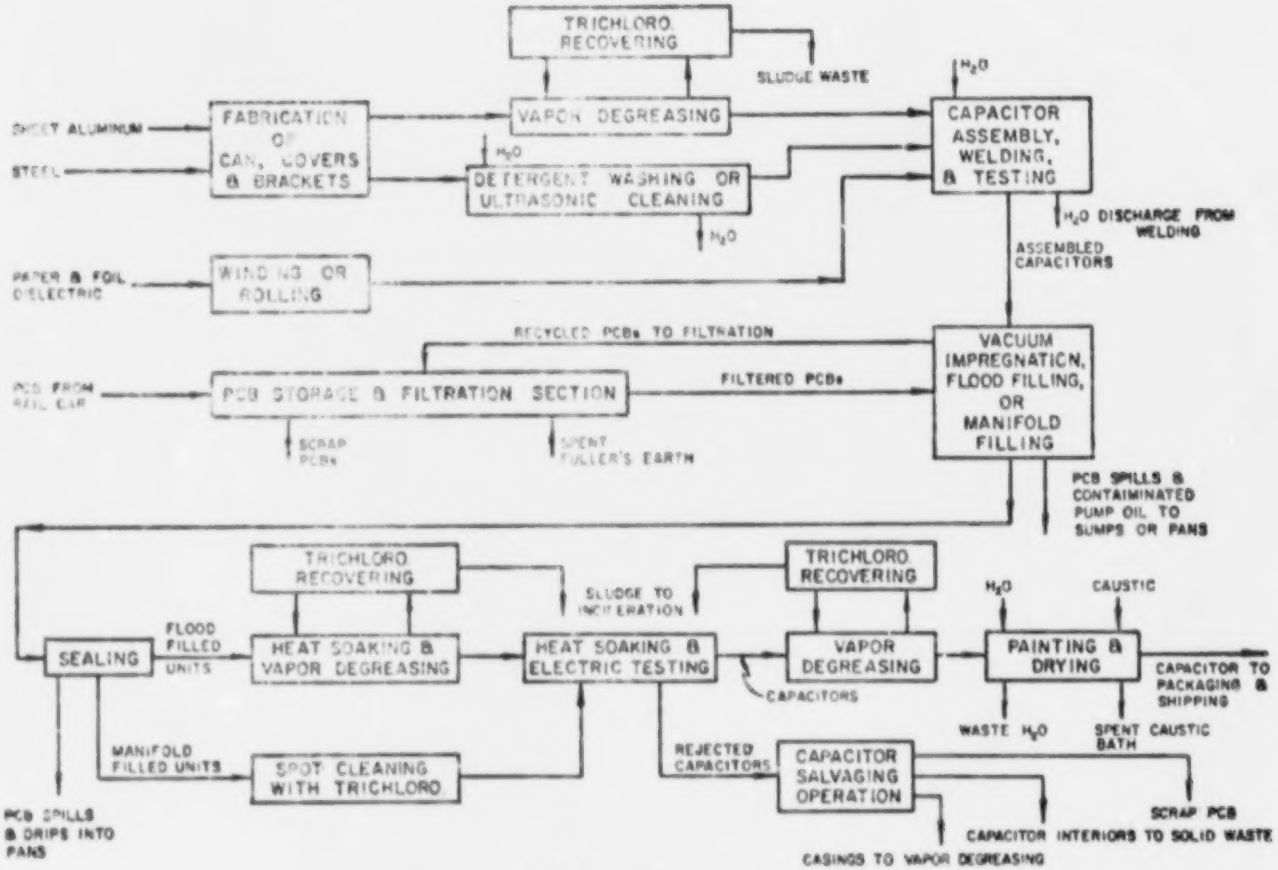

SHEET ALUMINUM
STEEL
FABRICATION OF CAN, COVERS & BRACKETS
TRICHLORO RECOVERING
SLUDGE WASTE
VAPOR DEGREASING
H_2O
DETERGENT WASHING OR ULTRASONIC CLEANING
H_2O
H_2O
CAPACITOR ASSEMBLY, WELDING, & TESTING
H_2O DISCHARGE FROM WELDING
ASSEMBLED CAPACITORS
PAPER & FOIL DIELECTRIC
WINDING OR ROLLING
RECYCLED PCBs TO FILTRATION
PCB FROM RAIL CAR
PCB STORAGE & FILTRATION SECTION
FILTERED PCBs
SCRAP PCBs
SPENT FULLER'S EARTH
VACUUM IMPREGNATION, FLOOD FILLING, OR MANIFOLD FILLING
PCB SPILLS & CONTAIMINATED PUMP OIL TO SUMPS OR PANS
TRICHLORO RECOVERING
SLUDGE TO INCINERATION
TRICHLORO RECOVERING
H_2O
CAUSTIC
SEALING
FLOOD FILLED UNITS
HEAT SOAKING & VAPOR DEGREASING
HEAT SOAKING & ELECTRIC TESTING
VAPOR DEGREASING
PAINTING & DRYING
CAPACITOR TO PACKAGING & SHIPPING
CAPACITORS
WASTE H_2O
SPENT CAUSTIC BATH
MANIFOLD FILLED UNITS
SPOT CLEANING WITH TRICHLORO
REJECTED CAPACITORS
CAPACITOR SALVAGING OPERATION
SCRAP PCB
CAPACITOR INTERIORS TO SOLID WASTE
CASINGS TO VAPOR DEGREASING
PCB SPILLS & DRIPS INTO PANS

FIGURE 3·2·1·2—1

GENERALIZED FLOW DIAGRAM FOR THE MANUFACTURING OF LARGE CAPACITORS

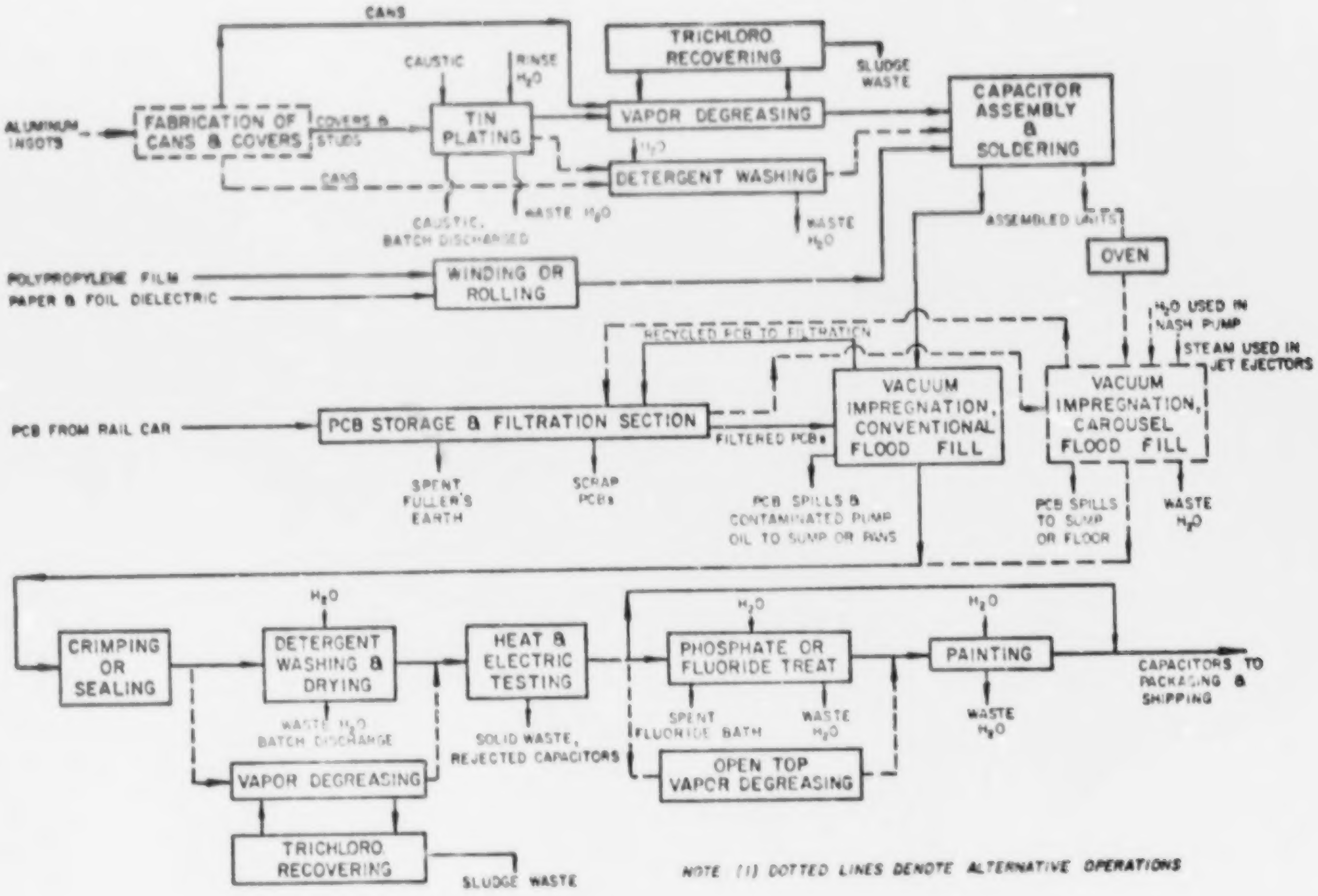

ALUMINUM INGOTS
FABRICATION OF CANS & COVERS
CANS
COVERS & STUDS
CANS
CAUSTIC
RINSE H2O
TIN PLATING
CAUSTIC, BATCH DISCHARGED
WASTE H2O
TRICHLORO RECOVERING
SLUDGE WASTE
VAPOR DEGREASING
H2O
DETERGENT WASHING
WASTE H2O
CAPACITOR ASSEMBLY & SOLDERING
ASSEMBLED UNITS
OVEN
POLYPROPYLENE FILM
PAPER & FOIL DIELECTRIC
WINDING OR ROLLING
RECYCLED PCB TO FILTRATION
PCB FROM RAIL CAR
PCB STORAGE & FILTRATION SECTION
SPENT FULLER'S EARTH
SCRAP PCBs
FILTERED PCBs
VACUUM IMPREGNATION, CONVENTIONAL FLOOD FILL
PCB SPILLS & CONTAMINATED PUMP OIL TO SUMP OR PANS
H2O USED IN NASH PUMP
STEAM USED IN JET EJECTORS
VACUUM IMPREGNATION, CAROUSEL FLOOD FILL
PCB SPILLS TO SUMP OR FLOOR
WASTE H2O
CRIMPING OR SEALING
H2O
DETERGENT WASHING & DRYING
WASTE H2O BATCH DISCHARGE
VAPOR DEGREASING
TRICHLORO RECOVERING
SLUDGE WASTE
HEAT & ELECTRIC TESTING
SOLID WASTE, REJECTED CAPACITORS
H2O
PHOSPHATE OR FLUORIDE TREAT
SPENT FLUORIDE BATH
WASTE H2O
OPEN TOP VAPOR DEGREASING
H2O
PAINTING
WASTE H2O
CAPACITORS TO PACKAGING & SHIPPING
NOTE (1) DOTTED LINES DENOTE ALTERNATIVE OPERATIONS

FIGURE 3.2.1.2—2

GENERALIZED FLOW DIAGRAM FOR THE MANUFACTURING OF SMALL CAPACITORS

(1) Conventional flood filling of capacitors

This type of filling operation is used for impregnating large power and small industrial capacitors. Here the capacitors are arranged in baskets or in large tanks which are subsequently transferred into vacuum chambers. Vacuum is then drawn and the capacitors are kept under vacuum at an elevated temperature for a specific period of time in order to evaporate the moisture from the capacitor interiors. The temperature of the tank is next lowered and PCBs are introduced under vacuum. The capacitors are allowed to soak for some time after which they are transferred to the sealing or crimping station via mobile car, sealed, and excess PCBs are then drained. The sealed capacitors are next sent to vapor degreasing or detergent washing for cleaning the exterior of these units. The clean units are heat soaked and heat tested in an oven and then sent to 100% electrical testing.

Subsequent to electric testing, the capacitors with steel casings are pretreated prior to painting. The pretreatment is either vapor degreasing for painting in an electro-static field or it is several stages of phosphatizing and rinsing operations, prior to automatic spray painting, where water is used to scrub the vapors generated during painting. Most capacitors with aluminum casings are marketed unpainted. However, at some plants a portion of capacitors with aluminum casings are fluoride treated and then spray painted. The capacitors are next either air dried or dried in an infrared oven prior to packaging and shipping.

(2) Automatic Flood Filling Operation (Carousel)

In this method of capacitor impregnation, the assembled units are placed in ovens for the removal of moisture from the capacitor interiors. The baskets containing these capacitors are next transferred to the carousel chamber which is at the loading position. The carousel passes through 13 subsequent cycles consisting of various degrees of vacuum applications and then subsequent PCB filling and soaking positions. The PCBs are next drained out of the chamber, and the capacitor baskets are removed from the vacuum chamber and tilted to drain excess PCBs in a sump located adjacent to the carousel loading and unloading station. The capacitors are next transferred to the crimping or sealing stations. From this point on the remainder of the manufacturing steps are identical to those employed in conventional flood filling operation.

In general, vacuum in conventional flood filling operations is achieved via mechanical pumps, whereas vacuum in each automatic flood filling station is achieved via a vacuum pump and several stages of steam jet ejectors.

Rejected industrial capacitors are disposed of in 55 gallon drums either directly or after disecting. Rejected power capacitors which are flood filled are returned to the salvaging operation. Here the capacitor covers are cut on an end mill, the PCBs drained and the interiors examined to find the cause of the electrical failure. Where possible the rejected units are then repaired and reprocessed. Otherwise, the capacitor interior is discarded in a designated solid waste drum. The capacitor casing is sent to vapor degreasing and it is subsequently sold to a scrap dealer.

(3) Manifold Filling Operation

At some plants, large capacitors are filled by this method. Here, the capacitors are completely assembled, sealed and vacuum tested; then each unit is filled individually under vacuum through a manifold. The capacitor valve is next sealed, the exteriors spot cleaned with trichloroethylene and then these units are transferred into an oven where they are heat soaked for a given period of time prior to electrical testing. Those capacitors which pass the electrical tests successfully are vapor degreased, painted, dried, packaged and shipped. The rejects are returned to the filling station where the majority of the PCBs are retrieved through the fill valve under vacuum. The rejects are next transferred to the salvage operation.

Mechanical pumps are used throughout the system to achieve vacuum.

3.2.1.3 Raw Wastes

The raw wastes originating from these plants consist of scrap PCBs collected in sumps, drums and drip pans, contaminated vacuum pump oils, the fractionator bottoms from the trichloroethylene recovery, the caustic bath used, at some plants, for purposes of paint stripping, spent detergent wash and rinse water from capacitor or component cleaning operations, rinse water used in the welding and plating operations, steam condensate from jet ejectors, the seal water used in vacuum pumps, water used in phosphatizing and fluoride baths, water spray used in the paint booths, boiler blow downs and cooling tower blow downs.

Furthermore, at least in one plant in this category water infiltrating at a subgrade elevator shaft creates an additional waste stream.

Solid wastes from these plants consits of scrap capacitors or capacitor interiors, floor dry and rags and newspapers used for cleaning spills, spent fuller's earth and other filtering media used for PCBs filtration and waterless cleaners used at some plants for hand cleaning purposes.

Non-product PCB discharges, their source and disposition are given in Table 3.2.1.3-1. Adequate data to quantify the various wastes generated at these plants is not available. Information on waste loads reported by some plants are given in Table 3.2.1.3-2.

3.2.1.4 Water Use

The water used at these plants is in the range of 12,500 to 1,260,000 gallons per day. In most plants, water is used primarily for once-through non-contact cooling in vapor degreasers, in pumps and in vacuum tanks. Plant 101 recycles their non-contact cooling water through a cooling tower.

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TABLE 3.2.1.3-1. NON-PRODUCT PCB DISCHARGES

Source	Plants 100	101	102	104	105	106
Vacuum pump exhaust	Air	Air	Air	Air	Air	Air
Evaporation & ventilation	Air	Air	Air	Air	Air	Air
Vapors from last stage of jet ejectors	None	None	None	None	Air	None
Personal hygiene	Sewer	Sewer	Septic tank	Incineration²	Incineration¹	Sewer
Laundry water	None	None	Septic tank	None	None	None
Water phase from pump oil/water separator	Sewer	None	None	None	None	None
Sanitary & domestic water	Sewer	Sewer	Septic tank	Sewer	Septic tank leach field system	Sewer
PCB contaminated water	River		Treatment plant then river	River	River	Sewer
Non-contact cooling water	River	Recycled	Treatment plant then river	River	River	Sewer
Rainfall & surface runoff	River	Storm sewer	Treatment plant then river	River	River	Storm Sewer
Rinse water from component detergent washing	None	Dry well	None	River²	None	None
Water used in non-PCB electrolytic capacitor operations	None	None	Treatment plant then river	None	None	None
Ground water infiltration	None	None	None	Decant then to river	None	None
Controlled sink drains³	None	Sewer	None	River	River	None
Rinse water used in the caustic bath & welding	None	None	None	River	None	None
Water used in paint scrubbing	None	None	None	Decant then to river	River	None
Phosphatizing bath & rinse	None	None	None	None	River	None
Scrap oil in drip pans, drums & sumps	Incineration	Incineration	Incineration	Incineration	Incineration	Incineration
Spent fuller's earth, clay & filter cartridge	Incineration	None	Incineration	Stored on site	Stored on site	Landfill
Rinse water from dry-well	None	Incineration	None	None	None	None
Fractionator bottoms (sludge) from trichloro recovery	Incineration	None	Incineration⁴	Incineration	Incineration	Incineration
Spent detergent wash of capacitor exteriors	None	Landfill	None	None	Incineration	None
Spent fluoride wash	None	None	None	None	Incineration	None
Reject capacitors or capacitor internals	Landfill	Landfill	Landfill	Stored on site	Stored on site	Landfill
Waste paper, floor dry & rags	Landfill	Landfill	Landfill	Stored on site	Stored on site	Landfill
Caustic bath	None	None	None	Stored on site	None	None

Notes: ¹Sinks in the impregnation areas are contained; water from the sumps are sent to incineration.
²Rinse water from non-PCB component washing operation.
³Employees are advised to use waterless hand cleaning material prior to washing their hands.
⁴Only liquids from this operation are sent to incineration. The sludge from this operation is sent to a municipal landfill.

TABLE 3.2.1.3-2 QUANTITY OF WASTE LOADS
(lbs/ton of PCB used)

	Plants					
	100	101	102	104	105	106
Land Destined Waste	73(1)	129	65	-(4)	-(4)	-(5)
Wastes to Incineration	100	56	98	109	127	300
Spent Fuller's Earth to Incineration	4.1	None(2)	-(3)	-	-	Unknown

Notes:

(1) Reported as PCBs. We estimate an additional 175 lbs/ton of PCB contaminated solid material which is being landfilled locally.

(2) PCBs are filtered through packed Porocell cylindrical filters. The filter media has an estimated life cycle of 20 year.

(3) This plant uses clay for PCB filtration. The quantity of spent clay sent to incineration is not known.

(4) These plants store their solid wastes consisting of spent fuller's earth, rejected capacitors, rags and floor dry, on site. Plant 104 generates ten 55-gallon drums of waste and plant 105 forty 55-gallon drums of waste each week.

(5) The weight of materials sent to landfill is not known. However, this company reports that during 1974 approximately 650 capacitors were rejected. The rejected units were drained and then sent to a landfill.

Process water used at various plants consists of water used in detergent washing, in ultrasonic washing, condensate from the steam jet ejectors, seal water from the vacuum pumps, water used in phosphatizing and in fluoride baths and rinses, and water used in caustic treatment and painting operations. Additionally, water is used for sanitary purposes and in some plants it is also used as boiler feed.

The quantities and types of water used at these plants are given below:

	Plants					
	100	101	102	104	105	106
Intake gallons/day	740,000	12,500	1,000,000[1]	1,260,000	480,000	336,500
Water Usage in gallons/day						
Non-contact cooling	655,000	3,000[2]	388,000[3]	1,195,000	387,000	326,500
Process water						
Rinse water from hot solder dip	200	-	-	-	-	-
Detergent washing & rinsing	-	8,000	-	25,000[4]	200	-
Phosphatizing baths	-	-	-	-	400	5,000
Water used in tin plating	-	-	-	-	12,000	-
Fluoride bath & rinse	-	-	-	-	50	-
Water used in painting					50	-
Pump seal water & steam condensate					44,000	-
Sanitary	44,940	1,500	52,000	10,000	65,000	5,000
Boiler feed make-up	40,000	-	-	30,000	15,000	-

Notes: (1) 560,000 gallons/day of this water is used as process rinse water in non PCB associated, electrolytic capacitor operation
(2) Make-up water
(3) It has been estimated that only 150,000 gallons of this water is associated with the plants PCB operation. The balance is used in the manufacture of Mica capacitors
(4) It includes water used in paint stripping and welding operations.

3.2.1.5 Wastewater Treatment

The major in-plant PCB wastes which reach water streams originate in the impregnation areas. Due to the nature of water requirements in this industry, at some plants it is possible to significantly reduce the quantities of wastes entering the water systems by adoption of proper housekeeping measures. Since there is no demonstrated technology available for the terminal treatment of PCBs in wastewaters, there are no PCB wastewater treatment techniques currently in use at any facility. Details on wastewater treatment techniques used at various facilities for purposes of oil recovery or neutralization and on-going containment programs undertaken by some plants to prevent the entry of PCBs into the environment are covered below.

Plant 100

In 1971-75, in-plant modifications were initiated to control PCB discharges from this facility. These modifications consist of repiping for scrap recovery, consolidation of processing and PCB handling area, and the installation of an oil/water separator for the recovery of contaminated oil used in their vacuum pumps. The water from this seperator is discharged into the municipal sewers. The recovered oil which contains PCBs is used as supplemental fuel in their boiler.

The plant's water effluent, consisting of primarily once-through non-contact cooling water, is discharged into a single trough on their property and from there it enters into a river. Their air conditioning condensate is discharged into a second trough and from there into the river.

Boiler blowdowns and water from the oil/water separator is combined with their sanitary water and discharged into the municipal sewers.

The only containment measure underway at this plant for prevention of PCB spills is at the Aroclor unloading area where provision is being made for a welded metal pan ([illegible] x 18" wide x 1" high) to catch pump oil and Aroclor spills. [illegible] a weather tight cover and will be periodically emptied and [illegible]ted.

Plant 101

This plant segregates non-contact cooling water from process water. The non-contact cooling water is recycled back to the system through a cooling tower. The process water consists of the water used in the detergent washing operation. The spent detergent wash is drummed, sealed and sent to a landfill. The rinse water from this operation is sent to the municipal sewers.

This plant practices "control sink" measures. Their employees are advised to use waterless cleaners for cleaning their hands prior to washing.

Plant 102

In addition to askarel and non-PCB impregnated capacitors, plant 102 manufactures electrolytic capacitors. Therefore, this plant has a three pond system for the treatment of the plant effluent. The entire plant water discharge, with exception of their sanitary water, is sent to a large concrete basin for pH adjustment. The overflow from this basin is routed to a 200 ft x 160 ft x 20 ft deep lake which has a retention time of 2 to 3 days. The overflow from the lake is sent to a 380 ft x 230 ft x 20 ft deep aeration pond which is equipped with mechanical aerators for BOD control. The overflow from this last pond enters the town creek and eventually ends in a river. Additionally, an oil skimmer is installed upstream to the treatment plant to remove oil from the effluent.

The plant is currently undergoing several modifications to minimize PCB entry into the river. The containment pits, located within the impregnation areas, are being sealed and access to the drainage system removed. Cooling water from pumps and tanks is being rerouted and dumped elsewhere. Vapor condensates, oil drips from vacuum equipment, and spills and scrub water are collected and held within these containment pits.

Plant 104

The only effluent treatment currently employed at this plant is a decanting operation used for the treatment of the paint stripping rinse water and the ground water infiltration.

Recent in-house modifications related to PCB control are as follows:

- A discharge line which passed under the tank farm area has been plugged and replaced with a new line bypassing this area to avoid further contamination of the effluent by infiltration.
- The discharge from the welding wash operations is segregated from storm drainage and diverted into the main plant outfall.
- The caustic bath, which was previously discharged into the river, is drummed and sent to incineration.
- Curbing and diking have been constructed around the tank farm area.
- An automatic monitoring station has been installed on the major outfall from this plant.

Additionally, as a housekeeping measure, two sinks in the impregnation room and one in the salvage recovery room used by personnel handling PCBs are contained. The wash water from these sinks is drummed and sent to incineration. Other sinks in the adjacement areas are designed as controlled sinks and personnel using these sinks have been instructed to use a waterless hand cleaning material prior to washing their hands.

Other containment programs to prevent the entry of PCBs into the environment are underway at this plant. The projected completion date of the entire program is by the end of 1976. Major modifications planned are as follows:

- Segregation of cooling water from process water and the installation of cooling towers for the recycling of the non-contact cooling water.
- Consolidation of all discharges to achieve a single plant outfall.

- Elimination of underground roof drain systems.
- Provisions will be made for the treatment of plant exhausts from all PCB related operations using a dry filtration system.
- Provisions will be made for a covered sheltered area for PCB loading and unloading area to prevent the rain runoffs from this area.

Depending on the success of the above mentioned modifications, a terminal PCB treatment facility may or may not be installed at this facility.

Plant 105

Recently this plant has made several modifications at their various manufacturing steps in order to minimize the PCB entry into the environment. The detergent wash and rinse water, which were originally sent to the river, are now contained and incinerated. The trenches near the detergent wash machines have been plugged to prevent discharge into the river. These trenches are periodically pumped out and the material sent to the scrap oil tank. Containment sink and control sink operations have been instituted in and around the impregnation areas. The condensate from the jet ejectors and the seal water from the vacuum pumps are directed to a 55 gallon drum which contains kerosene for the extraction of PCBs from the contaminated water. The decant from this drum is discharged to the river. At the tank farm area all gravel surfaces have been replaced with concrete.

Other containment programs to prevent the entry of PCBs into the environment are underway at this plant. The projected completion date of the entire program is by the end of 1976. Major modifications planned are as follows:

- Segregation of non-contact cooling and process water and provision for recycling of cooling water through a cooling tower.
- Segregation of uncontaminated storm water runoffs, with direct discharge to river.

- Provision for exhaust treatment using a dry filtration system.
- Collection of all sanitary water and the treatment of this effluent with activated sludge, aeration, clarification and chlorination prior to the terminal treatment for PCB removal.
- Filtration and carbon-adsorption of the plant's process water, sanitary effluent, and contaminated storm water runoff to achieve best practical levels of PCB treatment prior to discharge of the plant effluent into the river.
- Installation of a recycling system on their detergent washers. This system consists of gravity settling and sand filtration and is anticipated to minimize the frequency of detergent wash incineration.
- A garage shelter area will be erected at PCB unloading area. Additionally, the underground scrap PCB tank will be replaced by an above grade and larger tank.
- A recycling system is also planned for the vacuum pump seal water to minimize the quantity of process water discharged.

A three-week pilot operation of activated carbon adsorption, preceded by filtration, has been just completed at this plant. The mobile pilot unit was provided by a vendor. The samples from this operation are currently being analyzed to evaluate the performance of the system as a terminal treatment system for PCB removal.

Plant 106

This plant practices no end-of-pipe wastewater treatment techniques. The in-house PCB control operation is, however, an efficient means of eliminating contaminant losses to process or to sewers.

At this plant the raw PCB storage tank and its appurtenant distribution pump/filtration system is located within the confines of an approximately 52,000 gallon containment basin. Approximately 35,000 gallons of capacity in this basin is available for collection of scrap PCBs. The PCB contaminated material from this basin is ultimately shipped to a contract incineration facility.

The excess PCB from the impregnation system is drained by vacuum through an overhead pipe to a return sump and is pumped back through a Hilco filter to the storage tank. The interiors of the impregnation tanks have collection pans below the capacitors and spilled PCBs are drained from these pans into five gallon buckets for return to the contaminated storage sump. The PCB spills to the floor of the impregnation tanks are drained through the piping system back to the contaminated PCB sump. Oil dry is used outside of the impregnation tanks to minimize tracking.

Any byproduct or spillage resulting from the filtering operation is contained in the collection sump. The filter media is currently disposed of by landfill.

In addition, no water use is allowed in PCB handling areas. However, the impact of personal contact (that is, carrying it to wash basins, home, etc. on shoes, clothing and skins) may be a significant source.

The plant's tank truck unloading area is a curbed bay approximately 15 by 68 feet. Storm water that collects in the unloading bay can either be discharged onto the ground adjacent to the bay or into the 35,000 gallon contaminated PCB recovery sump. The valves from the storage bay area are padlocked and chained; therefore, only authorized personnel operate the valves. The overall goal that plant personnel try to achieve is to minimize the storm discharge from the bay by allowing evaporation. If a large quantity of water is believed contaminated, the drain valve to the contaminated PCB collection sump is opened.

Personnel representing plant 106 are of the opinion that there is no way to achieve zero discharge of PCB type contaminates to the environment. Therefore, there efforts have been directed toward development of a replacement type dielectric as opposed to exploring treatment systems for potential discharge problems at their facility. The plant personnel believe that with cooperation of a dielectric fluid supplier they have developed a suitable replacement product for PCBs. Attached as Appendix A is the company's positive statement on this substitute.

3.2.1.6 Effluent Composition

Effluent from plants in this category range between 2500 to 1,260,000 gallons per day. As indicated in the waste treatment section, these effluents are sent either into receiving waterways or into municipal sewers without any PCB treatment. Available information on effluent flow rates and their PCB contents, for most plants in this category, are given in Table 3.2.1.6-1. More detailed effluent information were obtained on four plants and Table 3.2.1.6-2 compares the discharges from these plants. Table 3.2.1.6-3 lists PCB concentration of the plant intake water from various sources.

It is of interest to note that one plant (plant 100) reported large variations in the PCB content of the receiving waters even at the time when the plant was not in operation. They attributed the variations to storm conditions, stirring-up the sediments from the bottom of the river and greatly increasing the PCB concentration in the water phase.

3.3 Askarel Transformer Manufacturing Industry

All plants in this category manufacture transformers using mineral oil as the dielectric fluid. This dielectric fluid is the principal impregnant used at these facilities. PCB transformer oils (blends of 60 to 70 percent Aroclor 1254 or 1242 and 40 to 30 percent trichlorobenzene) are used in only 5-10 percent of these plants' manufacturing volume.

In general, a transformer consists of a core and coil immersed in a dielectric fluid. There are two broad classifications of transformers: distribution transformers, which are used to step down voltages, and power transformers, which are used primarily to step up voltages. The precipitation power supply units can be actually classified as a third class of askarel transformer. However, the larger plants in this category have only two manufacturing departments — distribution and power; and they manufacture the precipitator transformers in their distribution transformer department. The following types of askarel transformers are manufactured at these plants:

TABLE 3.2.1.6-1 RANGE OF FLOW RATES & PCB CONCENTRATION IN EFFLUENTS FROM CAPACITOR MANUFACTURING PLANTS

Plant No.	Outfalls	Effluent Flow Rate gal/day	Effluent PCB Content ppb avg/max	Effluent PCB Content lbs/day avg/max	Disposition of effluent
100	001	800,000	17/55	0.1134/0.3670	River
101	None	9,000	161/161	0.0121/0.0121	Sewer
102	001	807,000	9	0.0605	River
	002	165,000	3.2	0.0044	River
	003	36,000	3.4	0.0010	River
104	Major outfall	1,060,000	21	0.1856	River
	Cooling water & roof drains	100,000	7.8	0.0065	River
	Lab & roof drains	32,000	4.4	0.0011	River
	Compressor cooling water	72,000	3.7	0.0022	River
	Paint strip rinse	50	4800	0.0002	River
105	Major outfall	650,000	370	2.0[illegible]58	River
	From spray paint booths	1,500[1]	13,300	0.1664	River
106	None	336,500	26.6	0.075	Sewer
107	None	150,000	1900/4000	[illegible]769/5.7546	Sewers
108	Cooling water & boiler blowdown	48,000	45/108	0.0180/0.0432	River
	Cooling water	129,000[2]	339/705	0.3636/0.7[illegible]	Sewer
	Roof runoff	2,900	1360/2370	0.3290/0.05[illegible]	River
	Storm runoff	unknown	3/11	- -	River
109	001	100,000	57/83	0.0475/0.0692	River
110	None	2,570	821	0.0176	Sewer
111[3]	None	18,000	8.7	0.0013	Sewer
112[3]	None	10,224	130	0.0110	Sewer
113	001	12,000	14.3	0.0014	River
126	None	580	6200[3]	0.03	Sewer

Notes:
(1) Discharged once every 4-5 weeks.
(2) Contains 20,000 gal sanitary sewage and 6000 gal of surface water infiltration
(3) These facilities recycle most of the non-contact cooling water used in the plant. These effluents consist of a small fraction of the cooling water plus their sanitary discharge.

Table 3.2.1.6-2

Comparison of Discharges

Plant	**100**	102			104				**105**
Outfall	001	001	002	003	002	003A	003B	006	004
pH	7.3	7.4	7.3	7.2	6.5-12.0	5.5-9.8	4.0-9.1	6.8-11.6	5.5-8.6
TSS, mg/1	3	16.6	1.54	2.8	5.2	4.7	4.0	3.1	9.5
PCB, ppb	17	9	3.2	3.4	21	7.8	4.4	3.7	370
Oil & Grease, mg/1	UK	3.10	3.38	2.18	7.20	14.40	30.70	2.66	12.8
Aluminum, mg/1	UK	ND	ND	ND	0.15	0.06	0.11	2.0	
Lead, mg/1	<.05	UK	UK	UK	UK	UK	UK	UK	UK
Copper, mg/1	<.003	UK	UK	UK	0.03	0.02	0.04	0.03	UK
Chromium, mg/1	<.005	UK	UK	UK	0.003	ND	ND	ND	0.03
Phenols, mg/1	<.001	UK	UK	UK	UK	UK	UK	UK	UK
Iron, mg/1	<.19	UK	UK	UK	0.29	0.30	0.34	1.66	0.52
BOD, mg/1		4.37	2.45	1.7	UK	UK	UK	UK	UK

ND - Non detectable
UK - Unknown

Table 3.2.1.6-3

Intake Water PCB Concentration

Plant	100	101	104	105	106	111	112
Source	Municipal	Municipal	River	Well Water	Municipal	Municipal	Municipal
PCB, ppb	0.09-2.5	4-7	57.0	40.0	0.25	1.0	1.0

A. Askarel Distribution Transformers

1. Network (Receive up to 14,400 volts and deliver 120, 240 and 480 volts)
2. Pad - mounted (Receive up to 14,400 volts and deliver 120, 240 and 480 volts)
3. Pole - mounted (Receive up to 14,400 volts and deliver 120, 240 and 480 volts) The application of these transformers in power distribution systems places a great premium upon their reliability and high overload capability.
4. Precipitator power supply (Receive 480 AC volts and deliver 50-60 kilovolts low amperage DC) These units are generally installed close to hot gas stacks in an atmosphere that would be a fire hazard to oil-insulated transformers and a corrosive hazard to open dry-type transformers. Sealed dry-type transformers are impractical for high-voltage DC.

Voltages listed cover the majority of askarel distribution transformers. Product scope includes up to 34,500 primary volts and virtually any secondary voltage, 34,500 and below.

Quantities of askarel used in this class of transformers are in the range of 500 to 5,000 lbs. in each unit depending on the rating and the size of the transformer.

A great majority of distribution type transformers have provision for venting. Many of these units are equipped with spring loaded venting devices which vent upon a pressure excursion, and diaphragm rupture discs are offered as a customer option.

B. Askarel Power Transformers

1. Secondary substation
    - (a) Load center units
    - (b) Secondary substation generation units

    (c) Switchboard units
    (d) Internal units
    (e) Motor control units

These 5 comprise the largest group of askarel-insulated transformers and they find widespread application in the automobile, paper, chemical, textile, steel, nonferrous metal, cement, mining and petroleum industries. They are used in commercial and public buildings, such as schools and hospitals; in defense and nuclear energy installations; and by private and public utilities.

2. Master unit substation
3. Primary unit substation
4. Limited ampere substation
5. Industrial furnace

Furnace transformers used in the hot, dirty atmosphere in proximity to glass melting and induction furnaces, which require high current, low voltage power supplies (receive up to 15,000 volts and contain 2000 to 4000 lbs. of askarel each). Existing technology does not permit construction of sealed dry-type transformers for these power ratings.

6. Rectifier

Rectifier transformers used for large rolling mills and DC industrial power supplies (receive up to 15,000 volts AC and deliver low voltage high amperage DC. Each unit contains about 19,000 lbs. of askarel). These units are covered by the same comments given for industrial furnace transformers.

7. Transportation

Railroad transformers used on-board in electric locomotives or multiple unit electric railroad cars (receive up to 25,000 volts and contain 700 to 2400 lbs. of askarel in each unit depending on the rating and size of the transformers).

(a) Third rail

These transformers are used for rapid transit systems, and are basically serving a rectifier function

(b) Locomotive

Prior to 1932, all on-board transformers were open dry type. Because of problems with them, railroads went to askarel-insulated transformers. The changes in locomotive design since the 1930's would not now accomodate open dry-type transformers as replacements for askarel units. A recent trend has been to replace askarel by oil units, and this will continue unless new Department of Transportation regulations require nonflammability.

However, since a tunnel fire in 1940 caused by an oil filled locomotive transformer, Penn Central will not allow any oil containing transformer equipped locomotive into New York City.

(c) Multiple-unit car (MU)

These transformers are mounted under the flat-bed of passenger cars. They ride along in this location, about 8 inches above the rail, at speeds up to 150 mph. The transformer must be ruggedly built to withstand the impact of flying debris and constant vibration. Power to the cars is brought in through an overhead catenary and is fed to the underside of the car where the transformer, controls, and propulsion equipment are located.

Space and weight are critical in this application. There are only about 33 inches above the rail. The width of the transformer is limited by the width of the car.

Only oil- or askarel-insulated units would provide the required performance levels in the space available. As with locomotive applications, present Department of Transportation regulations do not restrict the use of flammable liquids, and the use of askarel units has been dictated largely by the economic considerations of fire insurance rates, and by Penn-Central safety regulations.

8. Reactors

These units provide reactance (receive up to 15,000 volts under normal operating conditions. During normal operating conditions, they deliver volts and current as received. During power surges they choke the voltage and deliver the normal output).

9. Grounding,transformers (receive up to 15,000 volts).

3.3.1 Transformer Manufacturing Plants

There are thirteen companies in the U.S. which manufacture askarel transformers at eighteen plants. The name and location of these plants are given in Table 3.3.1-1. Some plants manufacture various types of transformers described above and others manufacture only one specific line of transformers.

All plants in this category were contacted to obtain information on their waste water. Detailed information, however, was obtained on two plants, which were visited. The largest U.S. transformer plant (based on quantity of PCB use) was not visited because of lack of cooperation. The data base represents approximately 20 percent of the 1974 PCB usage for transformer application. The PCB usage in this category was 12,000,000 lbs. in 1974 (equivalent to 15.0 to 17.0 million lbs. PCB transformer oil). The PCB usage in individual plants is considered by these companies to be confidential information. The range of plant PCB usage was 975 fold in 1974. Plant ages range from three to eighty-five years.

The amount of askarel used in individual transformers ranges from 40 to 1500 gals. (516 to 19,350 lbs.) with an average of about 232 gals. (3,000 lbs.). G.E. estimates that the total askarel-insultated units that have

Table 3.3.1-1

U.S. Transformer Manufacturing Industry Using PCBs

Company Name	Location of the Plant
Westinghouse Electric Corp.	South Boston, Va. Sharon, Pa.
General Electric Company	Rome, Ga. Pittsfield, Mass.
Research-Cottrell	Finderne, N.J.
Niagara Transformer Corp.	Buffalo, N.Y.
Standard Transformer Co.	Warren, Ohio Medford, Oregon
Helena Corp.	Helena, Alabama
Hevi-Duty Electric	Goldsboro, N.C.
Kuhlman Electric Co.	Crystal Springs, Miss.
Electro Engineering Works	San Leandro, Calif.
Envirotech Buell	Lebanon, Pa.
R.E. Uptegraff Mfg. Co.	Scottsdale, Pa.
H.K. Porter	Belmont, Calif. Lynchburg, Va.
Van Tran Electric Co.	Vandalia, Ill. Waco, Texas

been put into service in the United States since 1932 is 135,000, and virtually all of these units are still in service. The lifetime-before-failure is often longer than 30 years, and almost all units that do fail are rebuilt and returned to service. The current production rate of askarel transformers is about 5,000 units per year.

3.3.1.1 Askarel Handling

Few plants in this category purchase PCBs and trichlorobenzene and do their own compounding. Most plants purchase pre-compounded askarel from Monsanto. Smaller plants purchase their askarel in 55 gallon drums, filter the askarel and pump directly into the transformer tanks. To large plants askarel is shipped via rail cars. Rail cars enter in a designated area at the plant site. Askarel is then pumped from the rail cars into the raw askarel storage tank. Any spillage in this area is cleaned by rags or floor dry. The raw askarel is next filtered through attapulgite clay or fuller's earth and is often passed through a plate and frame type filter for final cleaning and then stored in the finished product storage tanks. Spent clay or fuller's earth from this operation is drummed and stored on site or sent to a landfill.

In some plants, the entire storage area is located within dikes and curbs designed to contain at least the contents of the largest single tank plus sufficient free board to allow for precipitation.

At most plants the askarel is distributed from the tank farm area to the filling station, but at one plant (Plant 103) the finished askarel is next trucked from a covered/curbed storage area to an uncovered/bermed tank farm area. Here the truck enters a shelter area, and the askarel is then pumped from the truck into distribution storage tank.

Recycled askarel from the manufacturing operations are generally returned through pumps into a storage tank or into 55 gallon drums and from there it is either filtered for reuse or is sent to incineration if it is proved to be defective.

3.3.1.2 Process Description

Most plants manufacture all the hardware and components necessary for the transformer assembly. The transformer interiors and the containers are brought to the askarel filling stations where transformers are assembled, filled and sealed.

The filling operation is done in a designated station. At plants where small quantities of askarel are handled spills and drips are cleaned via floor dry or rags. At plants where large quantities of askarel are handled, filling operation is conducted on gratings located on sumps. All drainage is directed into these sumps. The sumps are inspected and cleaned periodically. All scrap askarel from sumps is pumped into drums and sent to incineration.

Various transformer assembling and filling procedures are being practiced throughout this industry. In general, the transformer assembling and filling operations consist of a predrying step for removing moisture from the transformer interiors, several stages of askarel filling and askarel topping, addition of electrical connections and bushings, electrical testing and sealing.

At plants where relatively small quantities of askarel are used, the assembly and filling procedure for distribution and power transformers are alike. Some plants manufacture only a given size of transformers (single tank size operations). At larger plants different assembling and askarel filling procedures are employed for various transformer subcategories. Some of the askarel transformer assembling and filling procedures practiced within this industry are described below.

3.3.1.2.1 Assembly and Askarel Filling Procedure for the Distribution and Power Transformers

A. Vapor Phase Drying Prior to Filling

This procedure is primarily used in the filling of network and pad-mounted transformers. The drying of the transformer internals is a vapor phase treatment with a kerosene-like petroleum distillate. A schematic flow diagram depicting this system is given in Figure 3.3.1.2.1-1. The assembling steps for these transformers include the following:

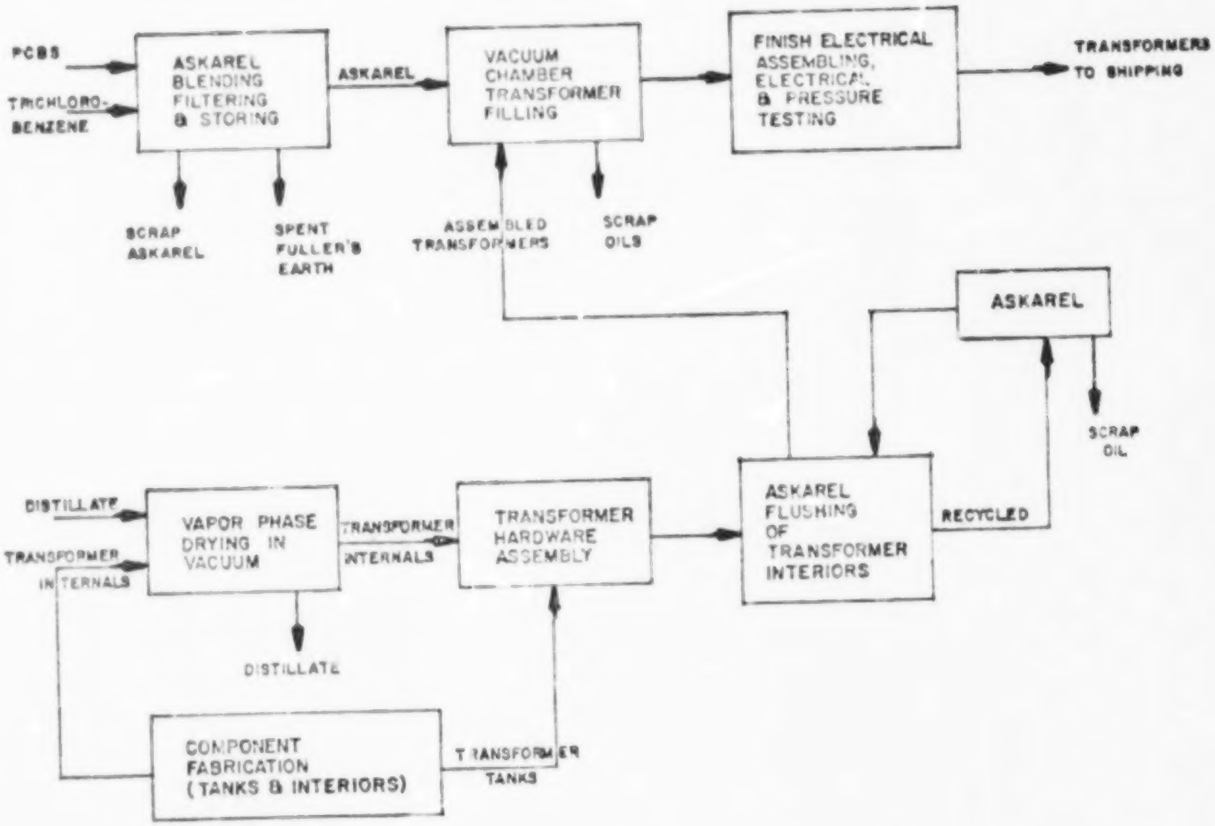

PCBS
TRICHLORO-BENZENE
ASKAREL BLENDING FILTERING & STORING
SCRAP ASKAREL
SPENT FULLER'S EARTH
ASKAREL
VACUUM CHAMBER TRANSFORMER FILLING
ASSEMBLED TRANSFORMERS
SCRAP OILS
FINISH ELECTRICAL ASSEMBLING, ELECTRICAL & PRESSURE TESTING
TRANSFORMERS TO SHIPPING
ASKAREL
SCRAP OIL
DISTILLATE
TRANSFORMER INTERNALS
VAPOR PHASE DRYING IN VACUUM
DISTILLATE
TRANSFORMER INTERNALS
TRANSFORMER HARDWARE ASSEMBLY
ASKAREL FLUSHING OF TRANSFORMER INTERIORS
RECYCLED
COMPONENT FABRICATION (TANKS & INTERIORS)
TRANSFORMER TANKS

FIGURE 3.3.1.2.1-1
TRANSFORMER FILLING WITH VAPOR PHASE PREDRYING OF INTERIORS

- First the transformer interiors are placed in large vacuum chambers heated with steam coils. The petroleum liquid is admitted, vacuum and heat are applied. The petroleum vapors rise to be condensed on the interiors, exchanging latent heat for sensible heat and raising the temperature of the interiors. After a specific time the liquid is pumped out; vacuum and heat are continued to dry the internals.
- The internals are next removed and placed in their own containers and flushed with askarel at atmospheric pressure. The askarel is kept in the tank until the liquid temperature is lowered to a preset level at which time it is pumped out of the tank. The purpose of askarel flushing is to chill the transformer interiors prior to final filling.
- The tank is next placed in a designated vacuum chamber. Vacuum is drawn and then fresh askarel is metered in slowly to avoid foaming or flooding.
- The vacuum chamber is next opened, the electrical connections are made and the liquid level in the tank is then brought to the operating level at atmospheric pressure. The transformer tank is then crane lifted and lowered on conveyors and sent to specified test stations for a series of electrical testing before the transformer is completely sealed.
- If a transformer fails the electrical tests, it is returned; the askarel is drained and reprocessed. Otherwise, the transformer is sent to cover welding operations.
- The tank is next lifted and sent back via conveyor belts to the filling station where it is topped with askarel through an access overhead pipe. The transformer is next pressure tested for leaks. The bottom drain valve is then sealed and the top opening is pipe fitted and sealed. Sealing is accomplished primarily by teflon

tape. However, for some transformers, the sealing is done by an air cured sealant at customer's request.

B. Oven Drying of Transformer Internals Prior to Filling

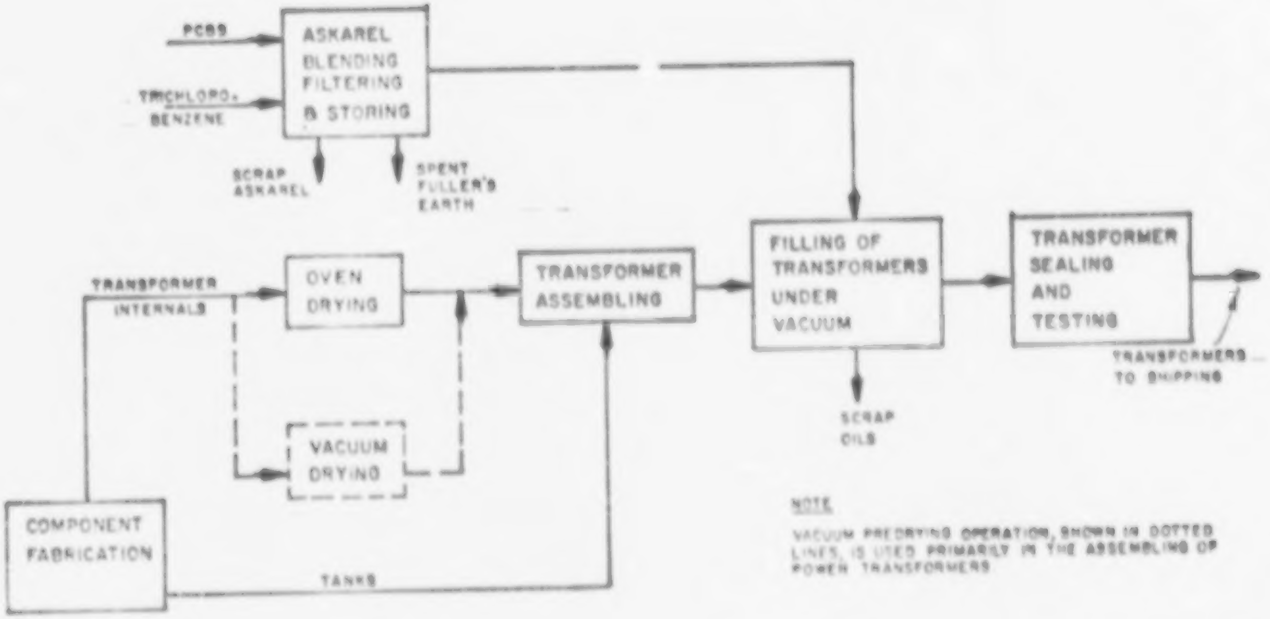
This procedure is used primarily in the assembly of pole type or precipitator transformers. The drying of internals for this category of transformers is accomplished in a convection oven. The internals are then placed in their own casings and the bushings and electrical connections are next made. Vacuum is then applied via a mechanical pump and the tank is filled with askarel while the transformer internals are still at a predetermined elevated temperature. Exhausts from this operation are pulled through a venting system.

Most transformers in this subcategory have gasketted covers with barrel band type connections. Subsequent to the filling operation, the transformers are sealed and pressure tested for leaks. The large units are liquid pressure tested while the smaller ones are air pressure tested. A schematic flow diagram depicting this system is shown in Figure 3.3.1.2.1-2.

The contaminated oil from the vacuum pump is treated as waste askarel and is sent to incineration.

C. Oven Drying of Assembled Units Prior to the Filling

This procedure is used primarily in the assembly of the precipitator transformers. Here the transformer internals are placed in their own casings, the covers are welded on the casings and the assembled tank is placed in the convection oven all sealed. At an elevated temperature, vacuum is applied at predetermined intervals. The tank is then transferred to the filling station where askarel is added through an upper pipe opening under vacuum. Both the top piping and the drain valve are next sealed and the unit is then pressure tested. A schematic flow diagram depicting this system is shown in Figure 3.3.1.2.1-3.


PCBS
TRICHLORO-BENZENE
ASKAREL BLENDING FILTERING & STORING
SCRAP ASKAREL
SPENT FULLER'S EARTH
TRANSFORMER INTERNALS
OVEN DRYING
VACUUM DRYING
TRANSFORMER ASSEMBLING
FILLING OF TRANSFORMERS UNDER VACUUM
SCRAP OILS
TRANSFORMER SEALING AND TESTING
TRANSFORMERS TO SHIPPING
COMPONENT FABRICATION
TANKS

NOTE

VACUUM PREDRYING OPERATION, SHOWN IN DOTTED LINES, IS USED PRIMARILY IN THE ASSEMBLING OF POWER TRANSFORMERS

FIGURE 3.3.1.2.1-2
TRANSFORMER FILLING WITH OVEN OR VACUUM CHAMBER PREDRYING OF TRANSFORMER INTERNALS

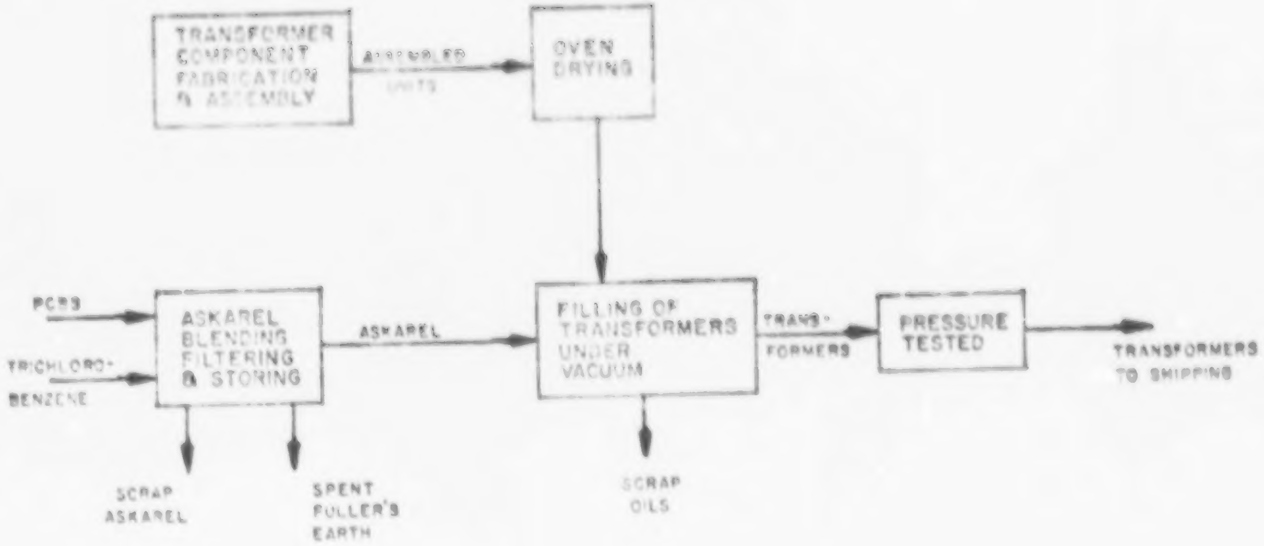

TRANSFORMER COMPONENT FABRICATION & ASSEMBLY
ASSEMBLED UNITS
OVEN DRYING
PCBS
TRICHLORO-BENZENE
ASKAREL BLENDING FILTERING & STORING
ASKAREL
FILLING OF TRANSFORMERS UNDER VACUUM
TRANS-FORMERS
PRESSURE TESTED
TRANSFORMERS TO SHIPPING
SCRAP ASKAREL
SPENT FULLER'S EARTH
SCRAP OILS

FIGURE 3.3.12.1-3
TRANSFORMER FILLING OPERATION WITH OVEN PREDRYING OF ASSEMBLED HARDWARE

D. Assembling Procedure for the Askarel Filled Power Transformers

The assembling procedure for all types of askarel filled power transformers is alike. Here, the transformer internals are dried in sealed vacuum tanks, then they are placed in their own containers and the cover is welded and sealed. The unit is then pressurized and checked for leaks via a helium detector. The tank is next transferred to the filling station where low vacuum is drawn for a period of 24 hours. The askarel line is then connected and the tank is filled slowly while under vacuum up to the operating level. The unit is then sealed and sent to electrical testing. After the tests the transformer is returned back to the filling station where it is nitrogen pressure tested just prior to shipping. The schematic flow diagram depicting this system is shown in Figure 3.3.1.2.1-2.

All power transformers have air space on the top and are equipped with an air cooled circulation system. Additionally, each unit has a spring loaded relief valve as standard equipment.

These transformers have a greater potential for environmental contamination through the vent system, via leaks on the pump and the valves.

3.3.1.3 Raw Wastes

In general, the process raw wastes from these plants consist of waste askarel collected in sumps or pans at the filling stations, contaminated vacuum pump seal oil, contaminated kerosene like petroleum distillate (used at least in one plant in vapor phase drying operation), contaminated askarel used for transormer interior flushing and contaminants in the plant water effluent.

Additionally, plant 103 has a unique waste stream consisting of contaminated ground water which is being pumped from three caissons at the plant site. Plant 103 has also a bleedwater discharge from their incineration system.

Solid wastes from these plants consist of rags and floor dry used for miscellaneous cleaning purposes and spent clay used for Aroclor filtration. Additionally, at plant 103 it includes the sludge from oil/water separators.

Non-product PCB discharges are shown in Table 3.3.1.3-1. Estimates on the quantities of raw waste generated in two plants which were visited are given below.

Quantities of Waste Loads	Plants 103	 114
Wastes to incineration, lbs/ton of PCB used	114	98.0
Solid waste material stored on site in 55 gallon drums	135 units	Unknown

3.3.1.4 Water Use

Water is not an essential component of transformer manufacturing process. PCB wastes which reach water streams at these plants are due to inadvertent occasional loss during handling and residuals accumulated around the drainage systems from past operations when no precautions were taken in handling and disposal of PCBs.

This category uses water primarily for non-contact cooling purposes in vacuum pumps, compressors and at some plants in contact cooling in their welding and plating operations and in phosphatizing of the steel surfaces prior to painting. All contact cooling operations listed above are primarily non-PCB related operations. Only plant 103 has a PCB related process water which consists of the water used in their waste incineration system for quenching the hot gases from the reaction section. Plant 103 is also the major water user in this category.

In most smaller plants all cooling is accomplished by air. At these plants water is primarily used for hygiene and sanitary purposes and for occasional compressor or pump cooling purposes. The only water that comes into contact with PCBs at these latter plants is that used for personal hygiene. The types and quantities of water used at two plants visited are given below.

Table 3.3.1.3-1. Non-Product PCB Discharges

Source	103	114
Plant exhaust	Air	Air
Incinerator exhaust	Air	None
Personal hygiene and sanitary water	Sewer	Sewer
Ground water pumped through caissons	To oil separators then river	None
Water used at plant	To oil separators then river	Sewer/river
Contaminated oils and waste PCBs	incineration	Incineration
Floor sweepings and rags used for cleaning	decapsulator	Incineration
Rejected transformer interiors for copper recovery	decapsulator	Stored on site
Contaminated and defective empty drums	To steel furnace in steel mill	Shipped to the company which handles their contaminated oils
Sludge from the oil separator	Stored on site	None
Clay used for adsorbent filtration	Stored on site	None

	Plant No.	
Water Usage in Gallons/day	103	114*
Non-contact cooling	1,646,000	38,000
Process water		
. Contact cooling	183,000	None
. Detergent washing	2,000	None
. Incineration quench	122,000	None
Hygiene	Unknown	300
Boiler make-up	Unknown	200
Sanitary	Unknown	9,000
Non PCB related		
. Water used in a lab	Unknown	500
. Water used for external cleanups	None	4,000

*Breakdown of the water usage was estimated.

3.3.1.5 Waste Water Treatment

There are no effluent treatment techniques in practice of any plant in this category for the removal of PCBs. Details on wastewater treatment techniques utilized at one facility (plant 103) for purposes of oil recovery and on-going containment programs undertaken by two plants (plants 103 and 114) in order to prevent the entry of PCBs into the environment are covered below.

Plant 103

Significant environmental controls have been reported at Plant 103. Since 1966, 3 men per year (two exempt and one non-exempt employees) are allocated to this effort.

In order to control oil losses to the environment, water/oil separator facilities were constructed on all major outfalls. Interceptor sewers were also constructed to reduce the number of discharges from approximately 35 to 10. All storm and industrial wastewaters from askarel manufacturing areas are served by two water/oil separators (separators 005 and 006). Each separator has a capacity of 2 million gallons. Each water/oil separator is divided into two longitudinal compartments. The wastewater enters the separator over a grating and passes through a drum basket type separator for the removal of large particulates. This drum is equipped with overhead water sprays to flush the particulates from the basket walls. The wastewater flows through the drum and crosses the length of the separator basin at which time the sludge settles and the oil is skimmed via two belt type oil skimmers, one on each separator compartment. This oil is recovered and used as supplemental fuel in the incinerator. The water phase passes a weir and enters the river.

The separators are effective during the plant's normal daily operation. However, during storms, in addition to the increased runoffs from the city areas the river water level rises and floods the system.

Other containment structures undertaken by this plant since 1966 include relocation of all bulk storage tanks within dikes designed to contain the entire contents of the largest single tank plus sufficient free board to allow for precipitation. Tank truck unloading stations include curbs and sumps adequate to contain the entire loss of tank truck contents. All new diked storage areas are drained by manually operated valves which are normally in the closed position.

All askarel storage tanks and distribution lines have been relocated above ground for ready leak detection and maintenance. In the few instances where pipelines are below grade, they are enclosed in sleeves to contain leakage.

In areas where the ground water is contaminated with oil, three caissons have been erected in the ground to pump the ground water into the water/oil separator for the separation of oil. The ground water from two of the caissons are treated in oil separator 006 and the water from a third caisson is diverted into oil separator 005.

Additionally, a John Zink designed thermal oxidation incinerator was erected at this plant in 1972 to safely dispose of PCBs. A schematic flow diagram of this unit is given in Figure 3.3.1.5-1. This unit consists of two steam atomized burners and a long cylindrical chamber to provide residence time for thermal degradation. Following the chamber is a water spray quench pot and a counter current packed scrubber column located at the base of the stack.

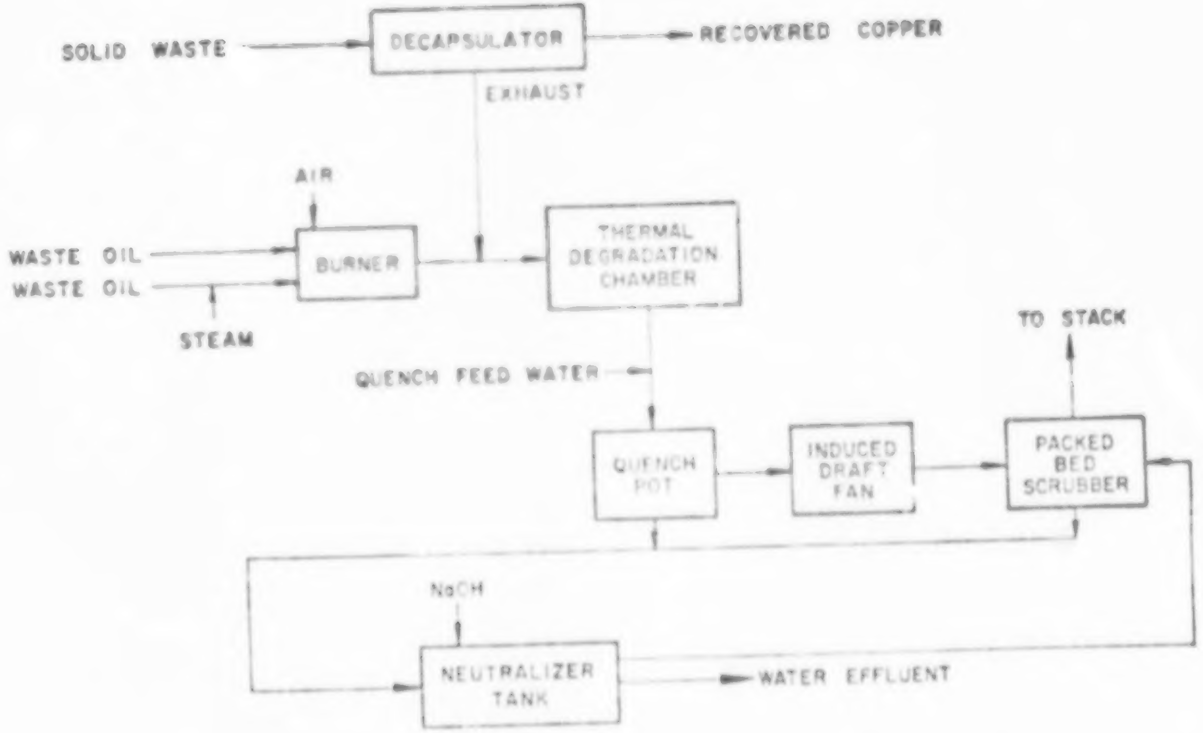

SOLID WASTE
DECAPSULATOR
RECOVERED COPPER
EXHAUST
AIR
WASTE OIL
WASTE OIL
STEAM
BURNER
THERMAL DEGRADATION CHAMBER
QUENCH FEED WATER
TO STACK
QUENCH POT
INDUCED DRAFT FAN
PACKED BED SCRUBBER
NaOH
NEUTRALIZER TANK
WATER EFFLUENT

Figure 3.3.1.5-1-PROCESS FLOW DIAGRAM FOR THERMAL OXIDIZER INCINERATOR AT PLANT 103

The waste oils are brought into the incinerator site in 55 gallon drums or by truck trailers. These waste oils are next pumped from the drums or from the trailers into the incinerator feed tanks. The steam atomizing burners inject the combustible liquid wastes into the combustion section with air, in such a manner to create a vortex type turbulence. This produces high heat release and effective combustion promoting the thermal degradation process. After combustion, the waste gases proceed through the oxidation chamber which provides 3 to 12 seconds of residence time at temperatures 1600 to 1800°F for the degradation reactions to go to completion. The flue gases from the chamber pass through a quench pot which contains a series of water sprays to cool the gases. An induced draft fan then forces the cooled gases through the packed bed scrubber column. Here, acidic ions produced during the combustion process are absorbed in the scrubber liquor. The scrubber liquor is then neutralized and disposed into the sewer.

A high temperature decapsulator has been incorporated in the thermal oxidizer unit for solid incineration and copper recovery. The exhaust of this unit is routed to the upper end of the oxidizer chamber.

Additionally, operating personnel are instructed on the operation and maintenance of equipment to prevent oil discharges; notices containing instructions for proper handling of PCBs are posted throughout the plant.

Water/oil separators are inspected and minor maintenance performed on a daily basis. All discharges are monitored on a regular basis as required by NPDES permits and data is compiled on a weekly basis.

Plant 314

This plant employs no wastewater treatment technique. However, their tank farm area is located in a 32 inch deep concrete basin which is completely imprevious. This basin is epoxy painted and all joints are sealed with Dow Corning "Silastic". Additionally, there is a second, inner, 12 inch deep basin around the askarel tank. The storm run-off from the tank farm area is accumulated in these basins. This wastewater is periodically pumped out and sent to incineration.

All oil receiving piping is made of welded steel. In order to prevent spills and leaks all sight glasses on their tanks have been removed and the fittings sealed. The oil volume in these tanks is determined by differential pressure.

3.3.1.6 Effluent Composition

Effluent flow rates and PCB contents are available from the three plants which discharge into the rivers and from two plants which discharge primarily into sanitary sewers. Detailed effluent composition is available only on Plant 103. This information is given in Tables 3.3.1.6-1 and 3.3.1.6-2, respectively.

The remaining plants in this category which discharge to sanitary sewers report that their water usage, for reasons other than for sanitary purposes, is minimal. However, they have no data available on the quantities and composition of water discharged.

Table [illegible] 3.1.5-1

PCB Concentrations in [illegible] Effluents from [illegible]
[illegible]

Plant No.	Discharge Description	Effluent Flow Rate (gal/day)	Effluent PCB Content: ppb Avg/Max	Effluent PCB Content: lb/year Avg/Max	Disposition of Effluent
101[1]	005 006	[illegible] [illegible]	4.9/120 [illegible]	[illegible] [illegible]	River River
114	[illegible] [illegible]	[illegible] [illegible]	Unknown Unknown	Unknown Unknown	Sewer River
[illegible]	00[illegible] 00[illegible] 00[illegible]	[illegible] [illegible] [illegible]	<1/2 [illegible] <2/[illegible]	<[illegible] [illegible] [illegible]	River River River
116[2]	#1 #2 #3	[illegible] [illegible] [illegible]	[illegible] [illegible] [illegible]	[illegible] [illegible] [illegible]	River River River
117	[illegible]	[illegible]	29.4/unknown	[illegible]	Sewer

Notes: (1) [illegible]

(2) [illegible]

(3) [illegible]

Table 3.3.1.6-2. Influent and Effluent Compositions of Plant 103

	Incoming Municipal Water	Outfall 005		Outfall 006	
Average flow rate million gpd	1.86	1.31		0.55	
pH yearly average	6.4	7.7		5.5	
pH min.-max.	—	6.4-8.0		3.1-7.1	
		Avg/Max Conc.	Avg lbs/day	Avg/Max Conc.	Avg lbs/day
Alkalinity, mg/l	14	25/25	273	15/20	69
BOD, 5-day, mg/l	2	3/3	28	27/30	124
Chemical oxygen, mg/l	9	23/34	251	75/92	344
TS, mg/l	69	70/70	765	364/497	1671
TDS, mg/l	68	67/67	735	341/483	1565
TSS, mg/l	1	3/9	31	23/30	106
TVS, mg/l	34	19/22	208	89/96	408
Ammonia, mg/l (AN)	0.05	<0.2/1.0	<2	2.8/3.0	13
Kjeldahl Nitrogen, mg/l	0.45	0.8/1.0	9	4.6/5.1	21
Nitrate AsN, mg/l	0.15	0.55/0.9	6	0.98/1.02	5
Phosphorus Total, mg/l	0.01	0.04/0.05	<1	54/124	248
Color (As P)	30	25/30	-	30/30	-
Turbidity, mg/l	<25	<25/<25	-	<25/<25	-
Total hardness, mg/l	44	31/44	340	33/44	152
Organic Nitrogen, mg/l	0.5	0.6/0.7	6.6	1.8/2.0	8
Sulfate, mg/l	9.0	14/18	153	9.0/9.0	41
Sulfide, mg/l	<0.1	<0.1/<0.1	<1.0	<0.1/<0.1	<0.5
Chloride, mg/l	6	6/8	61	11/13	50
Cyanide, µg/l	<0.00	0.00/<0.01	0.04	<0.00/<0.00	<0.02
Fluoride, mg/l	0.16	-	-	9.5/12.0	44
Aluminum - total, µg/l	100	500/550	5	200/200	0.9
Boron - total, µg/l	70	-	-	9/70	0.04
Calcium - total, mg/l	6.5	7.0/7.5	77	7.7/8.0	35
Chromium - total, µg/l	<10	30/30	0.3	310/350	1.4

Table 3.3.1.6-2 (Con't)

	Incoming Municipal Water	Outfall 005		Outfall 006	
Cobalt, total, µg/l	<7	4/4	0.04	-	-
Copper - total, µg/l	500	20/500	0.2	30/500	0.13
Iron - total, µg/l	330	150/330	1.6	3200/3500	15
Lead - total, µg/l	<30	<10/30	<0.1	80/90	0.36
Magnesium - total, µg/l	7	3/7	36	3/7	16
Manganese - total, µg/l	200	50/200	0.5	120/200	0.55
Mercury - total, µg/l	<1	<1/<1	<0.004	2/2	0.01
Molybdenum - total, µg/l	<7	-	-	90/95	0.41
Nickel - total, µg/l	100	<10/100	<0.1	10/100	0.04
Potassium - total, mg/l	1.1	0.88/1.10	9.6	0.99/1.1	4.5
Silver - total, µ	<10.0	-	-	2.0/2.0	0.009
Sodium - total, mg/l	5	6/10	66	25/30	117
Tin - total, µg/l	<7	7/10	0.07	-	-
Titanium - total, µ	2	-	-	3/3	0.01
Zinc - total, µg/l	30	70/75	0.76	730/800	3.4
Oil & Grease, mg/l	1.0	2/10	21	3.0/9.0	13.7
Phenols, µg/l	3	101/110	1.1	168/180	0.77
Surfactants, mg/l	<0.02	0.11/0.15	1.2	0.22/0.30	1.0
Chlorinated hydrocarbons, mg/l (except pesticides)	<1.000	1.000/5.000	11	1.000/1.000	4.6
PCBs, µg/liter	-	4.9/120	0.05	7/75	0.03

SECTION V

SELECTION OF POLLUTANT PARAMETERS

1.0 INTRODUCTION

This section discusses the pollutant parameters which are of significance to the polychlorinated biphenyls (PCB) production industry and those capacitor and transformer manufacturing operations which utilize PCBs as either dielectric fluids or cooling fluids. Historically speaking, both the production of PCBs and the utilization of these materials in electrical components have been considered industries with relatively inconsequential pollutional effects on the environment as a whole. However, in the recent past (perhaps the last five years) the significance of the buildup of polychlorinated biphenyls in the environment has become apparent. Ironically, the very properties which make polychlorinated biphenyls desirable for utilization in electrical components, i.e. relative inertness to physical, chemical and biological attack, contribute significantly to the undesirability of continuous discharge of this material to the environment. Following the recognition of the relative stability of this material and the buildup of PCBs in the environment, a broad spectrum of studies have been conducted by governmental, industrial and private institutions to determine the effects of PCBs on various levels of the eco-system. It is not the intent of this section to reiterate and confirm all of the claimed effects. Suffice it to say that a rather convincing body of information has been developed which indicates the potential mutogenic, teratogenic and carcinogenic properties of PCBs, particularly in higher life forms including human beings. In deference to the producers and users of PCBs, it should be noted that it is only with the benefit of rather recently acquired scientific data and a good measure of 20-20 hindsight, that the scientific community today is able to point to the rather poor control measures of these industries in the past as one of the causes for the relatively high level of PCBs found in the environment today. In other words, it is believed that the producers and users of PCBs should not be unduly chastised for their past handling of this material when little or no information was available to indicate that stringent control measures should be applied.

It can be categorically stated that the principal contaminant in wastewaters, solid wastes and scrap oils generated by the manufacture and use of PCBs are the PCBs themselves. Other constituents are of significance only to the extent that they (1) affect the properties of the PCBs contained in the wastes, (2) to the extent that other constituents interfere with the destruction or removal of PCBs from wastewaters, solid waste or scrap oils or, (3) to the extent that other constituents are contaminated with PCBs. In other words, there may be constituents added to wastewaters through manufacturing and production operations which themselves might need control in order to permit compliance with all applicable discharge and water quality standards; however, for the purposes of this evaluation and report, only those constituents which in some way affect the control of PCBs will be considered.

2.0 SIGNIFICANCE AND RATIONALE FOR SELECTION OF POLLUTANT PARAMETERS

As previously stated, the basic rationale employed in selecting those pollution parameters which are of significance in the production and utilization of PCBs was one of identifying those parameters which could in some way affect the control and treatment of PCBs. Each of the parameters which are considered of significance are listed in this subsection and the rationale for their inclusion are presented herewith. Again, it is not the intent of this section to list other pollution parameters which might require control in themselves, separate from that required for the control of PCB discharges.

2.1 Polychlorinated Biphenyls

As previously stated, PCBs are the principal contaminant of significance in all wastes generated in the production and utilization of PCBs. The principal sources of PCB contaminated waters, solid wastes and scrap oils from the PCB manufacturing operation and from the capacitor and transformer industry have been previously described in Section IV. The basic sources can be categorized as follows: (1) spills, leaks and drips associated with the handling, transport, storage of PCBs, (2) concentrates originating from the refining of PCBs, (3) scrub waters employed in systems associated with the incineration of scrap oils and PCBs, (4) vapors and condensates derived from the vacuum dewatering of PCBs in capacitor and transformer filling operation, (5) vapor degreasing and washing operations associated with the exterior cleaning of capacitors which have been flood filled with askarel, (6) handwashing and general clean-up by personnel who become contaminated with PCBs in the production operations, (7) other production operations such as paint stripping, painting, etc. which become incidentally contaminated with PCBs. There is, of course, also the PCB contamination of ground water and storm runoff from historical operations in which PCBs were employed. In other words, for existing facilities where PCBs have been employed for many years, continuous contamination of ground water and storm water runoff is possible through past losses of PCBs. It is recognized that general losses of PCBs to the atmosphere through local and general ventilation with subsequent redeposition of PCBs on the roofs and grounds of PCB utilizing facilities represent current and continuous potential contamination of ground and storm water runoff. Finally, depending on the ultimate philosophy regarding the control of PCB discharges from user facilities, the raw water supply employed by each user facility may in fact represent a source of PCB contamination.

2.2 Chemical Oxygen Demand (COD)

The non-specific parameter, chemical oxygen demand (COD) has been selected to identify other organic contaminants which might arise from the production or utilization of PCBs. COD is considered to be a significant parameter since it can affect the terminal treatment systems which have been identified as potential means of removing or destroying PCBs from contaminated wastewater. The two systems which have been identifed for terminal treatment include activated carbon adsorption and UV light assisted ozonation. In both of these cases, other organics as measured by the COD test will affect the terminal treatment system. In the case of activated carbon, such organics will occupy adsorption sites on the carbon and affect its rate of exhaustion. In the case of the UV-ozonation system, other organics as measured by the COD test will increase the required dosage of ozone to destroy the PCB since the ozone will be nonspecific with respect to the organic that it oxidizes. Some examples of the types of organic contaminants and their sources in the production and utilization of PCBs include: (1) other dielectric fluids which might be used in the same plant as PCBs including dioctylphthalate, castor oil, mineral oil, etc., (2) other organics which might be admixed with the PCB such as trichlorobenzene, (3) detergents which may be employed in cleaning operations particularly in electronic component production facilities, (4) solvents and organic pigments associated with the surface preparation and protection of capacitor and transformer cans, (5) vacuum pump oils, (6) and in some cases kerosene where aluminum rolling operations are conducted at the capacitor or transformer manufacturing site. Again, COD is considered a significant parameter since it does measure the increase in either carbon exhaustion rate or ozone dose required to effect removal or destruction of PCBs.

2.3 Fats, Oils and Greases

Free floating fats, oils and greases are considered to be a significant pollution parameter since PCBs are soluble in such materials. In removing these materials through the application of quiescent separation basins, the materials collected on the surface of such basins will require separate controlled destruction or disposal since they will be contaminated with PCBs. The sources of such materials have been cited under Subsection 2.2 (COD) and that portion of the oily materials which exceed their solubility in water are being referred to in this case. The separate handling and disposal of the materials which can be removed through gravity separation represent an add'l treatment and disposal cost and therefore fats, oils and greases are considered a significant pollution parameter.

2.4 Suspended Solids

It is recognized that PCBs have an affinity for adsorption on suspended solids contained in wastewater. There are basically two types of suspended solids which are of interest in this case. First, there are those which are of sufficient size and weight to permit their removal by gravity separation. Again, the sludges generated in the gravity separating operation would be anticipated to be contaminated with PCBs and would require separate destruction or disposal thereby adding to the total treatment cost. The second type of suspended solid which would be of interest in this case would be those which are filterable. As currently envisioned, terminal treatment schemes would include a filtration operation employing either dual or multi-media filters. The backwash waters from such filtering operations would be high in filtered suspended solids which would be anticipated to be contaminated with PCBs and would require separate treatment and disposal. The sources of suspended solids in the PCB manufacturing and utilization industries include filter media such as diatomaceous earth, clays, etc. and general floor dust generated in housekeeping operations.

2.5 Dissolved Solids

Dissolved solids or salts are relatively inconsequential with regard to nominal end-of-pipe treatment systems. However, in the case of "zero" discharge as defined in Section VII, the total dissolved solids level of the raw wastewater can become of significance when it is recognized that complete recycle is one means which is being considered for achieving zero discharge of PCBs. In the case of complete recycle, it is recognized that periodic blowdown of recycled waters will be required to prevent excessive buildup of the dissolved solids. Since the frequency of blowdown will be determined by the initial TDS level and the rate of evaporation of water from the system, the initial TDS level can become significant.

2.6 Other Constituents

Other constituents such as acids or alkalies which would affect the pH, possibly heavy metals, possibly other chlorinated hydrocarbons, etc., may in themselves represent constituents which would require control to place PCB producers and users in compliance with all applicable regulations. However, it is not believed at this time that any of these parameters affect directly the principal goal of the treatment systems to be described herein for the removal of PCBs. It should be recognized, however, that other treatment systems for controlling such parameters and the costs associated with such systems should not be overlooked in the total pollution control and wastewater management program for PCB-using facilities.

SECTION VI

WASTEWATER TREATMENT TECHNOLOGIES

1.0 INTRODUCTION

An analysis is made of the similarities and contrasts between the operations and waste control problems of the PCBs producer and capacitor and transformer manufacturing users. The major waste management or waste stream categories are summarized and a description is provided of the current control practices. Additionally, the candidate treatment technologies that were considered are presented as well as the rationale used in selecting the recommendations. This section concludes with the recommended control technologies for use immediately, within three years, and those that will not be available for five or more years.

1.1 Similarities and Contrasts Between PCBs Wastes and Control Practices in Their Production, and in Their Use as Dielectrics

Based upon detailed plant inspections and examinations of the process steps in the production of PCBs, and then their use in capacitor and transformer manufacturing, it has been determined that there are four major categories of wastes that must be considered. The categories will be described in the next section. It has also been determined that the characteristics of these wastes in PCBs production and dielectric manufacturing are similar enough so that the same kinds of control and treatment technologies can be used.

The manufacturer, Monsanto, does generate Montars and more highly chlorinated biphenyls as byproducts of the production process. These are separated from the product stream as part of the final preparation of the individual member products of the Aroclor series. Thus the capacitor or transformer manufacturer never encounters these highest boiling and most refractory PCB homologs and related compounds. However, these differences are not generally critical to the currently recommended treatment processes. There might be implications to incineration temperatures. They would have a bearing on the final development of several of the candidate more novel treatment methods that are still in the laboratory or pilot plant stages.

A minor contrast is that Monsanto produces and handles the pure Aroclors (mixtures of PCBs) and also blends them with trichlorobenzene to prepare askarels (non-flammable transformer fluids). Capacitor manufacturers handle only pure Aroclors, and transformer manufacturers handle primarily the blended askarels.

In production there are a number of ways that water streams come in contact with PCBs as part of necessary process steps.

However, in some of the dielectric users' manufacturing, there is rigorous exclusion of water from all steps to preserve the high quality of the dielectric device. Thus, the chances for those users to pollute water streams are very minimal and occur mostly through inadvertent drips or spills during askarel transfer, rather than during manufacturing steps which are all in a dry environment.

1.2 Summary of Waste Management Problem Areas

1.2.1 Waste Liquid PCBs and Contaminated Scrap Oil

The users of dielectric materials have strict requirements for purity. Typical requirements are:

Inorganic chlorides	100 ppb max
Acidity, mg KOH/g	0.01 max
Water content	30 to 35 ppm max
Resistivity, 100°C, 500 V, 0.1 inch gap	100 to 500 x 10^9 ohm-cm, min.
Dielectric strength, 25°C	35 KV min

When these or other properties cannot be met at the producer's facility, or after being used in the filling operation by the manufacturer and it is found that they cannot be restored to the askarel specifications by filtering and drying disposition is required.

As described in earlier sections, there are several categories of contaminated liquids:

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As described in earlier sections, there are several categories of contaminated liquids:

(1) PCBs contaminated with mineral oil;

(2) Mineral oil contaminated with PCBs; and

(3) Nonreclaimable contaminated transformer askarels - arced askarels, askarels from manufacturing spills and sump accumulations, and askarels from holding basins, drip and drain pans, washings, sample jars and containers.

1.2.2 PCBs in Wastewaters

Possibly the most universal pathways by which PCBs enter wastewater streams, are: 1) from operator wash-up after handling PCBs and 2) from outside groundspills that are blended into the next rainfall storm water. The importance of these pathways can be seen when we realize that if sixteen operators (or 4 operators 4 times a day) washed one ounce per day of PCB from their hands into the sanitary facilities, that would be one pound per day discharge. We did see situations occurring where operators get their hands immersed in PCBs; presumably most of this was wiped off in rags. However, if each of 100 employees in the area used 50 gallons of sanitary water in a day, that would be (50 x 100 x 8.34 lbs/day) or 41,500 lbs/day. The one pound of PCBs in 41,500 pounds of water would then give an averaged concentration over that day of 24.1 ppm in the sanitary stream (presumably solubilized by detergents).

Other categories previously discussed are:

1) Incinerator scrubber and quench water
2) Steam jet ejectors in vacuum distillation
3) Capacitor detergent wash solutions.

1.2.3 PCBs Contaminated Solid Wastes

These can be divided into two categories, burnable and nonburnable:

Burnable Solid Waste Materials Containing PCBs. These materials can be disposed of by high-temperature incineration and consist of cellulosic materials, rags, pressboard, wood, sawdust, fuller's earth in bulk or in cloth bags, blotter papers, nitrile or cork gaskets, and similar materials.

Nonburnable Solid Waste Materials Containing, or Contaminated with PCBs. These materials may consist of capacitors and transformer internal components; Steel, copper and aluminum components; filter units of the steel mesh construction type; and rejected drums and cans.

Materials of this nature should be allowed to drain, with the liquid collected in drip pans, before disposal.

1.2.4 Air Emissions of PCBs

PCBs although of very low vapor pressure can be emitted to the atmosphere from the following operations and practices:

1) Process scrubbing of air in PCBs manufacture
2) Vapor exhaust from steam jet ejectors
3) Evaporation from accidental spills
4) Evaporation from hot surfaces as part of flood-filling, or inspection or testing operations
5) Vacuum pump exhausts
6) Evaporation from plant wastewater.

1.3 Summary of Current PCBs Waste Control Practices

In Section IV of this report, the individual practices used by plants to control dissemination of PCBs to the environment have been described. This section summarizes the current methods of treatment being employed for the four major categories of wastes we have established.

1.3.1 Control of Waste Liquid PCBs and Contaminated Repair Oils

Plant visits, contacts and follow up investigations have shown the following to be the major control methods:

a) Incineration
b) Disposal in sealed drums to sanitary landfill.

Both incineration and landfill may be carried out by the facility generating the waste, or the facility may engage a contractor for the service.

Monsanto, the producer, has its own John Zink designed incinerator that vaporizes the PCBs liquids and maintains a turbulent burning gas at above 2200°F for about 2 seconds. One transformer manufacturer uses a John Zink designed incinerator, which vaporizes the PCBs and then burns at 1600-1800°F for 3 seconds or longer. This latter facility can also destroy PCBs soaked transformer intervals, but cannot routinely handle spent fuller's earth.

A number of PCBs users send all kinds of solid wastes to Rollins Environmental Services facility at Logan Township, N.J. Rollins uses a specially designed complex with a rotary kiln that exhausts to an afterburner plus a liquid turbulent burning chamber also exhausting to the afterburner. Liquids can be burned in both the liquid chamber and the kiln. In the kiln they are used to incinerate solids. The afterburner is 40 feet long, providing good residence time, but it is followed by a hot duct of about equivalent length that allows further combustion. Rollins claims a residence time of 3 to 4 seconds, at a minimum temperature of about 2400°F at the aft end of the hot duct. The gases then go to a venturi scrubber and a tower scrubber for cooling and neutralization. For non-PCBs incineration, Rollins sometimes lowers combustion temperature to 2200°F and residence time to 2 to 3 seconds. The facility operates with EPA approval. These residence times and temperatures were chosen experimentally to get 99.999% PCBs destruction. This facility also handles all kinds of solids as will be explained later.

Another facility that incinerates liquid PCBs, with New York State EPA approval, is the Chemtrol Corp.'s facility at Model City, New York.

Liquids going to landfill are sealed in drums and added to landfills that have deep clay bases, and impervious bulkheads to prevent leaching and seepage. However, incineration seems to be the preferred route for liquids.

1.3.2 Control of PCBs in Wastewaters

Our plant investigations have revealed that there are no methods being practiced whereby dissolved or otherwise bound PCBs in water streams are being either extracted from those streams, or destroyed in them.

As described previously, separations are made such that PCBs and sludges are removed from the bottom, and oily phases are removed from the surfaces of water bodies. However, nothing as yet is being done to the water layer itself.

This is the area of PCBs wastes control and treatment most needing investigation, development and reduction to practice of feasible, practical and economical methods for eliminating PCBs from all varieties of wastewater streams and collected bodies that are encountered.

In general, these streams will run from an undetectable level of PCBs (less than 1 ppb) up to about 500 ppb, with many instances being in the 10 to 50 ppb range.

Several plants are engaging in segregation measures to keep the quantity of PCBs contaminated wastewaters as low as possible. A few plants planned adsorption tests with carbons and other adsorbents, but there are no full scale operations.

1.3.3 Control of Solid Wastes Contaminated with PCBs

The two current practices observed for the disposition of solid or semi-solid PCBs wastes are incineration and landfill. Since we found only one dielectric device manufacturer with partial incineration capability, and Monsanto's incinerator cannot handle solids, all facilities except one must ship their solid wastes away from the plant site for either treatment. The one plant with partial capability can incinerate transformer internals to recover copper, and also can incinerate paper, rags, cardboard and the like. However, they do not as yet, incinerate fuller's earth, contaminated dirt, and similar materials. These are drummed and stored for later disposition.

Although there are a number of experimental facilities throughout the U.S. that could undoubtedly incinerate all types of solid materials, one commercial venture has received the bulk of the work. Rollins Environmental Services has been described above for liquids incineration. For solids incineration of almost all types, the tumble burner or rotary kiln is used. When PCBs contaminated materials are destroyed the kiln temperature is brought up to 2200°F. All kinds of solids, packed in 47 gallon lined fiber drums and not posing unusual safety hazards, are accepted. The current (late 1975) fee is about 7½¢/pound. Additional charges of $3/fiber drum handling, transportation charges, and possibly other charges for unusual problems might be made.

Rollins will not accept impact sensitive, radioactive materials, or heavy metals concentrations in the PCBs wastes of generally greater than about 25 ppm. For anything packed in steel drums, Rollins charges $10/drum handling charge.

As a general rule, anything packed according to the latest ICC tariff for hazardous materials will be accepted.

As with the liquids incineration, the gases from the kiln at 2200°F pass to the afterburner at a temperature of about 2500°F. They exit the afterburner to a long hot duct that completes combustion and maintains the temperature to 2400°F until the gases enter the venturi scrubber, and thence to the lower scrubber and then the stack. Rollins has experimented with lower temperatures of 2000 - 2200°F and has not found destruction of PCBs to the 99.999% level desired. The residence time for gases at the 2400° temperature is 3 to 4 seconds in a turbulent regime.

The other alternative for disposition of solid wastes is a controlled scientific landfill. Here again, one commercial venture has handled a large quantity of the PCBs solid wastes under supervised conditions.

The Chemtrol Pollution Services Co. of Model City, N.Y. operates a landfill located on the shores of Lake Ontario, under New York State EPA supervision, in a geologic setting that is claimed to be ideal for complete containment.

This "scientific landfill" is all located above ground on a bed of 40 feet thick clay. On this foundation, they construct cells for receipt of drummed solid wastes. The cells are lined with 30 mil thick chlorinated polyethylene film, and when loaded, they are sealed, or covered with five feet of clay. At the bottom of each cell there is a sump, so that all leachate is collected and removed from the cell. That leachate is pH controlled, settled, filtered, and treated by flow through a carbon bed. The ground and surface waters are checked monthly for chemical content by an outside analytical laboratory. The facility has been approved for usage as a PCBs disposal site by the New York State EPA, and thousands of drums have been landfilled over the last five years. An inventory is kept of the contents of each cell.

Chemtrol has the capability of converting semisolids and sludges to solids by using silicate cement powders and proprietary gelling agents.

Our review and analysis of the industrial situation for PCBs solid wastes control shows that there are adequate options, at a price, for safe disposal and destruction. There is no longer justification for open dumping to the ground or in lagoons.

1.3.4 Control of Air Emissions of PCBs

Most emissions from ambient temperature PCBs are not controlled or collected for treatment in any way. They generally are collected as part of the overall plant air exhaust, which frequently is ducted to roof exhausts without treatment. In a few isolated cases there was exhaust chilling and some fibrous or granular filtration of air with the potential for PCBs contamination.

In the hot flood-filling of capacitors there is a cool down at the end of filling, before the tank is opened to the plant atmosphere. However, the temperature is still probably 100°F to 150°F for a fraction of an hour, with a surface area of several square meters, with the filling tank open to the plant atmosphere. There are individual exhaust ducts at the tanks, but they lead directly to a roof exhaust system. Again the PCBs covered capacitors are held in an oven at 100 - 150°F to prevent any moisture condensation before sealing. Vapors from this storage are ducted to the roof and vented.

In some cases, waste scrap oils containing PCBs are burned together with fuel oil in standard boiler systems. In these instances much of the PCB content is probably vaporized and exhausted to the air, rather than incinerated.

2.0 CANDIDATE PCBs WASTE TREATMENT TECHNOLOGIES CONSIDERED

As part of the examination phase of this study of alternative methods, we have contacted a spectrum of equipment suppliers, developers, and even researchers, for both U.S. and foreign technology.

Key information was obtained about potential methods of PCBs removal from, and destruction in, wastewaters, by cooperative testing performed between Versar Inc. and several materials suppliers and process developers. Their assistance is gratefully acknowledged.

We visited the U.S. producer, Monsanto, and several transformer and capacitor manufacturers to ascertain the nature, characteristics and quantities of plant effluents that now contain measurable amounts of PCBs, or might contain PCBs following a spill or other incident. This has provided the background for weighing the advantages and disadvantages of all available technology for potential application to PCBs wastewater treatment. We discussed and evaluated the control methods they now use, their possible shortcomings, and ideas for better optimized systems.

In order to find the new technology and approaches that might be forthcoming; we conducted a computer search of Chemical Abstracts from 1972 to current 1975, which eliminated PCB synthesis, manufacture, or toxicology data and focused on bringing out degradation, decomposition and waste treatment data.

Searches were also made of the Lockheed Engineering Index, National Technical Information Service; and Predicasts for information on new business developments.

The text reference used as a source of summarized data prior to 1972 was: The Chemistry of PCBs, by Hutzinger, Safe and Zitko; published by CRC Press in 1974.

The candidate treatment technologies have been divided into the same four categories used under 1.2 and 1.4, above. Also, as we evaluated technologies, they were placed into categories indicating their readiness for usage as follows:

1. Demonstrated Full Scale Treatments
2. Pilot Plant Scale Methods
3. Research Approaches to PCBs Removal or Destruction.

Some of what is reported is work based on treatments of compounds similar to the PCBs, i.e., chlorinated hydrocarbons and other refractory organics.

The full scale plant treatments are ready for application to PCBs waste problems now. The pilot scale methods are expected to take one to five years to be developed to the point where they will be determined suitable, or unsuitable, for plant scale PCBs applications.

The research methods are expected to take three years or more before being ready for plant scale applications decisions.

In the latter part of this section (2.5) the applicability of various treatments to the zero discharge situation is discussed.

2.1 Treatment of Waste Liquid PCBs and Contaminated Scrap Oils

Only two kinds of treatment or disposal methods were considered suitable for this waste category; and they are the ones now being used. However, there are improvements and design features that are highly desirable to prevent PCBs transfers from this liquid state to water, air or land.

2.1.1 Incineration

A standard configuration of a long cylindrical steel combustion chamber, with a length to diameter ratio of 4/1 to about 8/1, well insulated with high alumina refractory brick is suitable for the primary chamber. Two burners should be provided; one for a high BTU exothermic combustion material such as gas, or a fuel oil, and one for the PCB waste liquid. Primary air or steam is provided to vaporize the oils, and secondary air is added to complete combustion and provide a measured excess of air. These feeds should be made tangentially, or with adequate baffling to assure turbulent flow throughout, and to prevent hot or cold spots in the chamber. It is obvious that almost any residence time may be calculated for a gas flowing through a cylindrical chamber. However, there will be a minimum flow rate and a maximum residence time for which turbulence is assured throughout the chamber. Turbulence throughout can be measured by uniform wall temperatures in all parts of the chamber. Most fuel flames will provide adiabatic combustion temperatures of about 3000°F. When the more endothermic PCBs are being destroyed, the flame can be rapidly cooled to 2200-2500°F. However, it has been found in a number of instances that for the very high destruction efficiencies desired, 99.999% or higher, this is the minimum temperature range required for a residence time of 3 to 4 seconds. Following the combustion chamber there should be allowance for afterburning, which may be accommodated in insulated ducts. These can be of sufficient length to assure the total residence time of 3 to 4 seconds. Following the combustion phase there must be rapid cooling of the gases with sufficient cold water, usually as a peripheral ring of sprays or jets. Also, at this point neutralization should be accomplished so that hot hydrochloric acid contact with further components is negated. At this point, some systems introduce a high energy venturi scrubber. This is particularly helpful if particulates are expected in the gas stream. In all systems the gas stream is then washed counter currently with water, or water plus neutralizing agent, in some form of a packed tower. Usually there is a demister as the last element contacted by the gas, before it is exhausted through the stack.

The stack gas emissions and the scrubber effluent liquid should be monitored periodically for PCBs levels.

The incinerator should have adequate automatic controls to prevent PCBs from being emitted undestroyed. The chief failsafe control is to have a burner shutdown if the pyrometer at the far end of the combustion chamber or duct drops below about 2150°F. There are a number of other controls that can be provided to warn that such an occurrence might take place. These would be flow rate controls on the primary and secondary feeds. Low fuel flow, or high PCBs-to-fuel flow ratio could lead to a temperature drop. Inadequate air flow could lead to the same difficulty. All such parameters should be monitored, and adequate operator warnings provided. Of course, to prevent destruction of the venturi and scrubber sections, shutdown should be automatic if cold water flow is ever insufficient.

2.1.2 Sanitary or Scientific Landfill

This method is an alternative to incineration for a PCBs user that cannot justify an incineration facility just for PCBs, and has no waste pickup service organization within reasonable distance. There is little room for variation in the kinds of landfill that will adequately contain PCBs. It should have all the desired features described in Section 1.3.3 above, but in addition, there must be high assurance that the liquid containers will be sealed and leak proof, and have long life in the landfill.

2.2 Treatment of Wastewaters Containing PCBs

This category of treatment has received the most attention in our study, because it has received the least attention in practice thus far. Our survey has found a variety of methods applicable to reduction or "zero discharge" of the quantity of PCBs disseminated to the environment by wastewaters.

2.2.1 Carbon Adsorption

This is a water purification and industrial product purification technique that has been widely used over a good part of the 20th century. The plant in Marshall, Texas that makes "DARCO" brand carbon for ICI-US was originally built in about 1912.

The early consideration of carbon adsorption as a means of removing PCBs from wastewater is logical and reasonable. Carbon adsorption is most effective in removing high molecular weight, non-polar, and relatively insoluble compounds from water. All these requirements are met by the PCBs.

As will be discussed later, we have conducted recent tests, in cooperation with carbon suppliers, showing the effectiveness of removal of PCBs from wastewaters such that reasonable effluent requirements could be met; say of the order of 1 ppb.

The apparent disadvantage in using carbon, that is still under investigation, is that once PCBs are adsorbed on the carbon, it may have to undergo destruction by high temperature incineration, rather than regeneration such as is normally practiced.

A great advantage of carbon treatment is that recent studies by Calgon and others have shown that a wide spectrum of other toxic organics can be effectively removed from water by activated carbon.

From practical operating and economic points of view, carbon adsorption is favored since it is currently being used in large scale municipal water purification systems. This gives good confidence in predicting capital and operating costs, and reliability factors.

At the 68th Annual AIChE Meeting in November 1975, G. Strudgeon of Zurn Industries described design features for a 30 million gallon per day carbon treatment system for municipal wastewater at Garland, Texas. This entire system will cost $5 million, including carbon regeneration. Operating costs are expected to be $6,000/day.

Although carbon adsorption is thus far the only mechanism that has been proven effective in removing PCBs, that same meeting provided data on three other mechanisms by which carbon has removed other pollutants from wastewater: 1) by biodegradation, when bacteria coated carbon particles, and then attacked pollutants in the wastewater; 2) by catalytic action, i.e., by providing a very active surface, and holding pollutant molecules while other degradation or oxidation reactions took place; 3) by chemical reaction, in which the carbon in the bed is actually depleted as part of a chemical reaction that removes pollutants.

The utility of any of these modes of activity for PCBs removal remains only a potential at this time.

As an adjunct to this evaluation study, we have conducted cooperative laboratory adsorption isotherm tests with Carborundum Company, and ICI-US. This gave new data on the removal of higher concentrations, and lower concentrations, of PCBs from wastewater for combination with the published data by Calgon.

Laboratory adsorption isotherm testing is a reliable technique for determining the feasibility of adsorption treatment for PCBs removal from wastewaters. This testing procedure specifically indicates:

1) The effluent levels of PCBs concentration obtainable by adsorption treatment.
2) The weight of PCBs that will be adsorbed by the adsorbent at the concentrations being studied.

On the other hand, the laboratory test is not used to determine the necessary contact time for granular carbon beds to effect the desired reduction. This determination is usually performed in small pilot carbon beds under dynamic hydraulic flow conditions--also, a well-established procedure is reported in the literature.

Laboratory and pilot plant tests of PCBs removal must be carefully carried out to prevent inadvertent losses of PCBs. The root of the problem is the very low, parts per billion, solubility of PCBs in water. Examples of pathways of experimental loss are:

a) Evaporation to the air; as described in 1.2.4; and
b) Adsorption on a variety of solid surfaces, sediments and the like.

2.2.1.1 PCBs Adsorption Testing by Carborundum Company

Versar Inc. together with Carborundum Co. conducted a preliminary study to determine the ability of an experimental, coal-based, activated carbon in removing PCBs from water. This study also provided an analytical check in that both companies ran electron captive gas chromatographic analyses on the same samples; and there was close agreement on results.

The activated carbon had a surface area of 950 to 1050 square meters per gram. The iodine number was approximately the same as the surface area, indicating that almost all of the pores had a diameter greater than 10 to 15 angstroms.

The control, and test samples were filtered before extraction and gas chromatographic analysis. The removal of PCBs by solids, surfaces, filter media, and the like, was appreciated before these tests, thus a high PCBs concentration in the filtered control was the target.

The PCBs used were the Aroclor 1254 mixture. It was solubilized by methanol to give a 1000 ppm stock solution. This was diluted with distilled water to prepare the 1000 ppb test solutions.

Table 2.2.1.1-1 presents the data. The filtered control level is considered the actual ppb level that the carbon was adsorbing, rather than the prepared level. The filter removed approximately 85 percent of PCBs in these test runs.

As shown in Table 2.2.1.1-1, the percent PCBs removal from a rather concentrated water solution (160 ppb), at low carbon dosages was quite good since during our plant Surveys we found PCBs concentrations in wastewater destined for river discharge to range from 50 to 500 ppb, the level treated in this study is an intermediate value. It is, however, the highest value treated in the cooperative studies under this program.

Carborundum Co. plans to continue this effort to determine the effects of other carbon dosage levels on various feed PCBs concentrations. The above reported data is only considered a preliminary effort.

2.2.1.2 PCBs Adsorption Testing by ICI-US

In a cooperative program with Versar, ICI-US performed preliminary adsorption tests to determine the ability of powdered carbon in removing Aroclor 1254 from water. Versar conducted all analytical tests for this program.

The Aroclor was solubilized with methanol so that a 1000 ppm concentration of Aroclor 1254 in water was achieved. Two types of granular activated carbon were tested: a lignite base, and a coal base. Both types were ground to a fine powder (90% through 325 mesh) before adsorption testing. Prior to grinding, the lignite base and coal base carbons had a surface area of about 650 square meters per gram and 1000 square meters per gram, respectively.

TABLE 2.2.1.1-1

CARBORUNDUM CO. TESTS OF PCBs (AROCLOR 1254) REMOVAL FROM WATER BY AN EXPERIMENTAL ACTIVATED CARBON

Prepared PCBs Concentration (ppb)		Carbon Dosage(1) (mg/1)	PCBs Conc. Before Treatment [Control Conc. After Filtering] (ppb)	Effluent PCB Conc. After Carbon Treatment (ppb)	Percent PCBs Removal
Control -	1000	--	160	—	--
Test	1000	1.0	160	59	63.1
Test	1000	2.0	160	20.6(2) 22.0(3)	87.1 86.2
Test	1000	10.0	160	2.6(2) 2.4(3)	98.4 98.5

NOTES: (1) Experimental material, coal-based, 950-1050 square meters/gram.

(2) Versar Inc.'s analysis.

(3) Carborundum Co.'s analysis.

The test solutions were made up with distilled, deionized water to a volume of one liter. Four levels of Aroclor concentrations were treated: 10 ppb, 100 ppb, 500 ppb and 1000 ppb. Both the control and treated solutions were filtered before analysis. The great affinity of PCBs for all solid surfaces was not fully appreciated, during these tests. The filtration was uniform for all samples through 2.4 cm Reeve Angel fiber glass discs (Grade 934AH). It can be seen in Table 2.2.1.2-1 that most of the PCBs were removed in filtration. However, by using the filtered "control sample" as an approximation of the amount the filter removes from all feed samples, we can get a good preliminary estimate of the PCBs removal ability of the two kinds of commercial carbons at varous wastewater pollutant levels, and at various carbon dosages.

The results of these laboratory tests indicated that powdered carbon was highly effective in removing PCBs from water at four levels from 1 to 40 ppb. There was not a great deal of difference between the effectiveness of the two carbons. The lignite carbon has relatively large pores, and a smaller surface area than the coal-based carbon. The lignite-based carbon simulates the activity of the coal-based carbon after a number of thermal regenerations. Thermal regeneration tends to increase the pore size, and lower the surface area of any given carbon. These kinds of activated carbons, however, tend to stabilize at about 550 square meters per gram, even after many regenerations.

The conclusion from these results is that carbon-adsorption can be an effective method of removing PCBs from wastewaters, even after many thermal regenerations.

It is quite significant that in all these tests, the treated effluent PCBs levels ranged from 90 to 320 parts per trillion, which are well below the target maximum PCB level of 1 ppb.

Further testing is needed to get confirmatory isotherm data and column test data. In column tests, the granular form of carbon

TABLE 2.2.1.2-1

ICI-US TESTS OF PCBs (AROCLOR 1254) REMOVAL
FROM WATER BY TWO TYPES OF COMMERCIAL CARBONS

Prepared PCBs Concentration (ppb)	Carbon Type	Carbon Dosage (mg/1)	PCBs Conc. Before Treatment (Control Conc. After Filtering) (ppb)	Effluent PCBs Conc. (After Carbon Treatment) (ppb)	Percent PCBs Removal
Control, 10	--	—	1.07	--	--
Test, 10	Lignite[1]	4	1.07	0.177	83.5
Test, 10	Coal[2]	4	1.07	0.190	82.2
Control, 100	--	—	11.15	--	—
Test, 100	Lignite	30	11.15	0.213	98.1
Test, 100	Coal	30	11.15	0.111	99.0
Control, 500	--	—	5.32	--	--
Test, 500	Lignite	100	5.32	0.09	98.3
Test, 500	Coal	100	5.32	0.114	97.9
Control, 1000	--	--	37.5	--	—
Test, 1000	Lignite	100	37.5	0.32	99.2
Test, 1000	Coal	100	37.5	0.24	99.4

NOTES: (1) Larger pore, 650 square meters per gram.

(2) Smaller pore, 1000 square meters per gram.

is used, and, therefore, some of the interior portions of the carbon are not as accessible as they are in the ground form. Thus, the tests with powdered carbon given on a weight fraction basis, i.e., pounds PCBs removed per pound of carbon is the maximum weight fraction of PCBs that can be removed in a scaled-up, commercial system.

2.2.1.3 PCBs Adsorption Testing by Calgon Corp.

Adsorption isotherms were run on Aroclor 1242 and 1254. Stock solutions of each compound were prepared in acetone at 100 mg/l. Filtrasorb^{R} 300 (FS-300) activated carbon was used throughout. Carbon was added from a stock suspension of 1 g or 2 g of pulverized FS-300 per liter of distilled water.

Isotherms of Aroclor 1242 and 1254 were prepared by the following method. Exactly 1 ml of PCB solution was added to seven flasks, each containing slightly less than 1 liter of distilled water. Measured volumes of the 2 g/l carbon stock solution was added to each flask to give carbon concentrations of 0,2,5,10,25,50 and 100 mg/l. The total volume of each flask was 1000 ml. After four hours agitation on a wrist shaker, each solution was filtered through 0.45 micron millipore pads and stored in a refrigerator in quart amber glass bottles with Teflon-lined caps until analyzed.

A nickel-63 electron capture gas chromatograph was used for analysis. All samples were extracted and concentrated approximately 100 times before analysis. The method is described in the 1971 EPA report, "Methods for Organic Pesticide Analysis in Water and Wastewater."

Table 2.2.1.3-1 shows the PCBs removal data, and gives comparative data for Aldrin. It appears that the Aroclors are removed similarly to the pesticides. Removal from the 50 ppb level to the 1 ppb level seems possible.

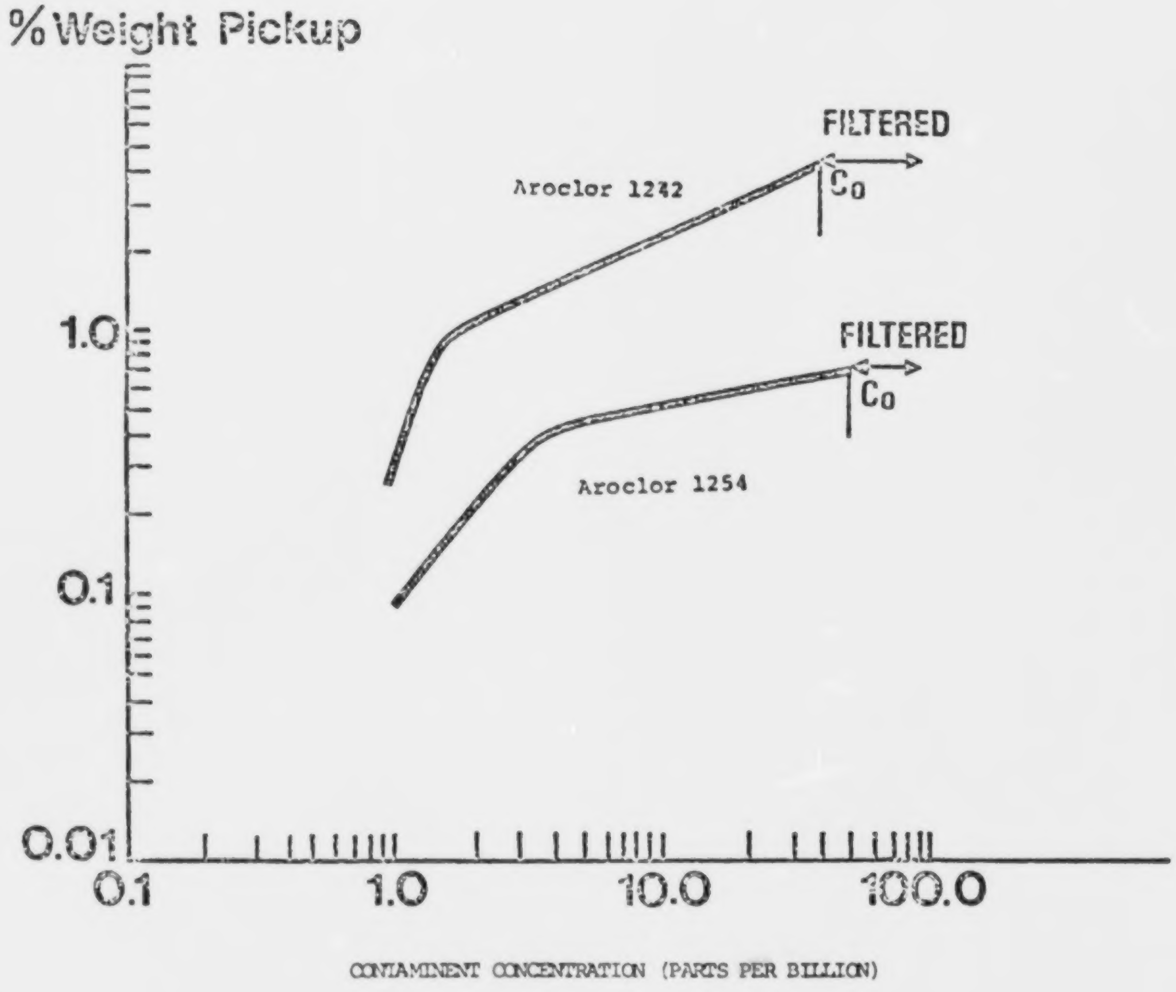
Figure 2.2.1.3-1 shows the Calgon data plotted to give the weight percent of PCBs that Filtrasorb-300 carbon can pick up, at levels down to 1 ppb. It can be seen that the curves take a downward break at about 2 to 3 parts per billion, indicating that the weight of activated

TABLE 2.2.1.3-1

RESULTS OF CALGON CORP. LABORATORY ISOTHERM TESTS FOR CARBON REMOVAL OF PCBs

Carbon Dosage (mg/l)	Residual (ppb)		
	Aroclor 1242	Aroclor 1254	Aldrin
Control	45	49	48
1.0	--	--	--
2.0	7.3	37	26
2.5	--	--	--
5.0	1.6	17	15
10.0	1.1	4.2	12
12.5	--	--	--
25.0	--	1.6	6.3
50.0	--	1.2	4.4

Figure 2.2.1.3-1. Equilibrium Carbon Adsorption of PCB's from Water At Low Concentrations (Calgon Data)



carbon required to achieve removal of a unit weight of PCBs is rising rapidly. If this kind of data is confirmed with larger scale column testing, it would mean that removal of PCBs from water in the parts per trillion range is far more difficult than removal in the parts per billion range.

Also from the figure it can be seen that the initial concentrations (Co) of the Aroclors to be tested were about 100 ppb. However, filtration before testing removed PCBs so that the starting concentrations for the tests were 45 and 49 ppb.

Hager and Rizzo of Calgon Corp. have described the essential elements of full scale adsorption systems in a paper presented to the EPA Technology Transfer Session on Treatment of Toxic Chemicals; Atlanta, Ga., 4/19/74.

Each system is comprised of three basic functional components:

1. The adsorption treatment of the wastewater
2. The carbon reactivation equipment
3. The carbon/water transport arrangement.

For PCBs, the practicality of reactivation must be determined.

2.2.1.3.1 Adsorption Treatment of the Wastewater

The adsorbers hold the granular activated carbon beds through which the wastewater flows. They can be designed for pressure or gravity flow to achieve the desired contact time of the water with the carbon. Suspended solids and space limitations also must be considered in the adsorber configuration. Flow rates usually fall under 10 gpm per square foot of carbon bed surface area. Contact times for industrial wastewater mixtures usually are in excess of 60 minutes, which is about twice the time employed for purification of domestic sewage. When suspended solids are present, they will be filtered out of the carbon bed. This dual purpose of carbon beds can be usefully employed as long as the adsorbers are designed to accommodate periodic backwashing and bed-cleaning procedures, such as air scour and surface wash. For PCBs service, minimum backwashing would be desirable, as it creates quantities of concentrated wastewater for incineration or treatment. Some settling and prefiltering will be required even when subjected to incineration.

A well-designed water distribution or underdrain will insure good backwashing performances as well as an even distribution of the water. Well established filtration design practices can be effectively employed in carbon bed design systems. Carbon beds must be periodically removed via water slurry and obstructions to the flow of carbon from the adsorber should be avoided in adsorber design.

Carbon beds are normally in excess of 10 feet deep and usually fall into one of four basic configurations:

1. moving beds
2. beds in series
3. beds in parallel
4. expanded beds.

The type of configuration selected depends on a number of variables; principal among them are total water flow, suspended solids, and degree of contaminant reduction desired.

2.2.1.3.2 Reactivation of the Granular Carbon

Thermal oxidation is generally employed to reactivate the exhausted carbon for reuse using either multiple hearth furnaces or rotary kilns. The size of the thermal reactivation equipment is based on the carbon exhaustion rate, i.e., pounds of carbon exhausted per thousand gallons of wastewater treated, and the weight of contaminant on the carbon. Excess capacity is designed into the thermal reactivation unit to allow for variances in carbon use rate due to changes in the wastewater flow and organic loading.

The exhausted granular activated carbon is heated to 1600-1800°F to effect volatilization and oxidation of the dissolved organic contaminants. Oxygen in the furnace is normally controlled at less than 1% to effect selective oxidation of contaminants over activated carbon. A 5% loss of activated carbon per reactivation cycle is an acceptable bench mark upon which granular carbon system economics may be based. Particularly for the PCBs which will require an incineration temperature in excess of about 2200°F, and a few seconds residence time, the reactivation equipment must include an afterburner. An air scrubber with HCl neutralization will be the last element of the reactivation train. Thus far, the regeneration of carbon that has seen PCBs adsorption service has not been proved.

2.2.1.3.3 Carbon Transport

Granular spent carbon is usually transported between the adsorbers and the reactivation equipment by water slurry. Various pumping designs can be employed including centrifugal and diaphragm pumps as well as movement using either hydraulic or pneumatic pressure. The transport piping should include flush ports and wide radius bends. About one to three pounds of carbon per gallon of water are used, depending upon distance and elevation considerations.

2.2.1.3.4 Materials of Construction

Special consideration should be given to the selection of materials of construction used in the adsorption system from two standpoints:

1. Galvanic Corrosion - any tendency toward galvanic corrosion due to water characteristics, such as conductivity and pH, will be enhanced in granular carbon beds. Mild steel tanks or adsorbers holding granular carbon under water should be lined; tanks can also be constructed of cement or reinforced synthetic resins or plastics.

Carbon-in-water slurry piping, which experiences only periodic exposure, is usually exempted from and special corrosion considerations.

2. Erosion - periodic replacement of the carbon beds can cause lining failures at exit ports in carbon tanks and adsorbers. Special grades of stainless steel are usually employed for such wear points.

2.2.1.4 Carbon Regeneration Alternatives - Wet Catalytic Oxidation

For smaller installations, it might prove feasible to dispose of the spent carbon by incineration. The carbon supply companies also offer services of removal of spent carbon, and off-site regeneration, when delivering fresh carbon.

However, there is a new wastewater treatment technique that might be applicable to carbon regeneration, and should be evaluated soon. This involves wet catalytic oxidation. Some of the laboratory studies in wet catalytic oxidation are described in Appendix D. Lockheed Missiles and Space Co. (Waste Treatment Systems Section) of Sunnyvale, California, announced in January, 1976, that they have a process ready for pilot plant evaluation and commercial scaleup.

In a very preliminary look at the PCBs destruction potential of this method, a sample of wastewater from an unnamed user of PCBs was subjected to treatment. The PCB mixture approximated Aroclor 1221 most closely. The wastewater sample was very concentrated, 5 ppm. Since this is much higher than that Arcolor's solubility in pure water it is believed that solubilizing agents or particulates were carrying most of the PCBs into the mixture. At any rate, within 20 minutes of treatment time, about 90% of the PCBs had been destroyed. No large quantities of reaction products were detected. However, this is just one data point and much further confirmation is needed. The test reactor was a continuously stirred batch system, with air continuously sparged in. The test conditions used were; reactor pressure, 1500 psig; temperature, 550°F; catalyst concentration, 0.5 gram; and reactor volume, 1.5 liters.

A proposed use of this catalytic system is for carbon regeneration when it is in the spent water slurry form.

Since the capital and operating costs of the catalytic system are tied to the hydraulic load, it might be practical to trap PCBs with carbon in wastewater, and then treat the carbon slurry by catalytic oxidation to destroy the PCBs. By this method, the PCBs would be removed from the wastewater by the highly efficient carbon adsorption method, and the volume handled by the catalytic system would be greatly reduced.

At this point, feasibility testing for regeneration of activated carbon by catalytic oxidation is needed. The activated carbon industry has long sought alternatives to thermal regeneration of carbon, because of its exposure and the loss of carbon by oxidation in that regeneration. Whenever they have tried solvent regeneration, or acid or base treatment, the first regeneration only produces about 40% of the active surface. This then drops to 30% usually after a few more treatments. Such a degradation is unacceptable. Thus, the points to be determined are: a) can this process destroy the adsorbed PCBs on carbon, converting them to CO_2, H_2O and HCl? and will the regenerated carbon have, say 90-95% of its original activity? and c) can the process be operated economically? The latter involves the necessary pressure (500 to 2000 psi), operating temperature (300 to 650°F), source of oxygen (air, O_2 or ozone), type and lifetime of catalyst, residence time, materials of construction, and similar variables.

2.2.1.5 Further Applications Data

ICI-United States provides an excellent booklet entitled "A Symposium on Activated Carbon", providing considerable detail on applications. They also provide information on special graphical procedures helpful in the scale-up from isotherm to column testing.

2.2.2 Ultraviolet-Assisted Ozonation

Both UV radiation, and ozone, separately, have been used in water purification for some time. It is only over the last five years or so that the synergism of the combination toward the destruction of organics in water has been appreciated.

Two commercial organizations: Houston Research, Inc., of Houston, Texas; and Westgate Research Corp. of Marina Del Rey, California are engaged in development of UV-assisted (or catalyzed) ozone oxidation of refractory organics. Both organizations have cooperated in preliminary tests of PCBs destruction, and the method has shown great promise as a viable, large-scale, economic water treatment method. They are working mostly with the 2537 Angstroms "near" UV radiation; but plan to investigate the "far" UV mercury radiation at 1845 Angstroms.

Of particular interest is the fact that these methods hold promise of destruction of hydrocarbon organics completely to CO_2 and water. Thus they are likely candidates for zero discharge and total recycle systems.

Related to this work is that of Dr. Lawrence of Environment Canada at Burlington, Ontario. He is concentrating on the near UV radiation of about 3650 Angstroms, available from sunlight, but using titania or alumina as photocatalysts, rather than the combination with ozone. The ultraviolet region extends to 3800 Angstroms, and then blends into visible violet. Other related work using visible light is described in later subsections.

Generally the UV radiation is provided by commercially available tubes, which when operated at low power (and low pressure in the emitting tube) are quite efficient in transferring UV radiation to water. The path length must be kept quite short, probably of the order of a few inches maximum, as the absorption in the water, and by even small amounts of particulate, will be nearly complete in that length.

Ozone is sparged into the reactor, and vigorous stirring is provided, to the point that increasing turbulence or mixing power input does not give an increase in reaction rate.

Various kinds of efficiency values are given to rate different systems, flows, arrangements, etc. Total organic carbon removed per watt-second of UV input, or per gram of ozone introduced, are examples of efficiency measures.

Since ozone generation is expensive, work is directed toward maximum use of the ozone introduced. The expense is almost completely the electric power expense of the silent discharge tube method of making ozone from air. Of course the UV expense is also an electric power expense.

The following subsections cover discussions on the general attributes of UV radiation and its molecular interactions, the photodegradation of PCBs, and finally UV-assisted ozonation experiments with PCBs.

2.2.2.1 Molecular Responses to Ultraviolet Region Energy

Energy absorbed in the ultraviolet (UV) region (100-3800°A; or 10 to 380 nm) produces electronic transitions within the molecule. The principal characteristics of an absorption band are its position and intensity. The position of maximum absorption (λ max) corresponds to the wavelength of radiation having energy equal to that required for an electronic transition. A molar absorptivity at maximum absorption (E max) of 10,000 or greater is regarded as high intensity absorption. Low intensity absorption is considered an E max of less than 1,000. Biphenyl in alcohol at 250 nm has an E max of 18,000; and in hexane at 246 nm, an E max of 20,000.

This would seem to indicate that the basic structure of the PCBs would be readily activated by a mercury lamp generating 253.7 nm radiation. However, this absorption will be modified by the number of chlorine atoms attached to biphenyl in forming the PCBs. If at any point in the destruction of PCBs saturated hydrocarbons are formed, they will be unresponsive to 253.7 nm radiation. Saturated hydrocarbons contain sigma electrons exclusively. Since the energy required to bring about ionization of the sigma bonds is of the order of 185 k cal per mole it is only available in the far ultraviolet, below 200 nm. Single carbon-carbon and carbon-chlorine bonds have about the same high bond energy, and are similarly stable to rupture. However, there is a mercury emission at about 185 nm, which should be capable of activating those bonds.

When irradiated by the proper UV wavelength, excitation of bonding electrons takes place, and free radicals are produced which are highly reactive in the presence of ozone.

Thus it appears theoretically possible to produce the excited states in PCB molecules necessary to make them highly receptive to oxidation by the emissions from mercury vapor tubes. Since ozone is a powerful oxidizing agent, and it too is excited in the same regions making it even more effective, the possibilities for a wide range of oxidations are present. This would seem to make complete destruction of PCBs to CO_2, water and HCl feasible.

2.2.2.2 Photodegradation of PCBs

Because of the strength of the C-Cl bond, it had been assumed for some time that little photochemical cleavage would occur. Further, in the photochemical breakdown of DDT and related compounds, cleavage of the aromatic C-Cl bond is usually not involved. However, Safe and Hutzinger reported in Nature in 1971, that a hexachlorobiphenyl photolyzed rather readily in organic solvents when irradiated at 310 nm. It gave products which are formed by stepwise loss of chlorine, rearrangement, and condensation. A number of additional researchers have found that some pure chlorobiphenyls and some PCB mixtures can be decomposed by laboratory UV sources and by sunlight over long time periods.

The wavelength of the UV source appears to be quite critical to successful photochemical decomposition. Low pressure mercury lamps emitting 2537 Angstroms (254 nm) seem to be several times as effective as the UV from sunlight which is greater than 2950 Angstroms (295 nm). Studies have been carried out in organic solvents and water, and in both liquid and vapor states.

Much of the past work has been on organic solvent solutions of PCBs to get higher concentrations to work with. Vapor phase studies have been run to simulate treatment of atmospheric emissions in environmental studies.

Reductive dechlorination, the main photoreaction of chlorobiphenyls, is faster in hydroxylic solvents such as methanol and isopropanol. Even chlorobenzene loses chlorine rapidly on irradiation in isopropanol. Nishiwaki, et al, observed complete dechlorination of a PCB mixture in 15 minutes in an alkaline isopropanol solution, using a mercury lamp. Biphenyl and sodium chloride were identified in the reaction mixture.

Photosensitizers can increase the decomposition rates. Tryptophan, diethylaniline, benzophenone and triphenylene sensitized the photoreaction of dichlorobiphenyl. The reaction was quenched by n-hexyl mercaptan and di-n-butyl sulfide. Experiments in water solution have been hampered by adsorption of the PCBs on the walls of reaction containers, particularly glass.

Attempts have been made to use surfactants to keep the PCBs in suspension. Adsorption on solids like calcium carbonate, silica, soils, etc. in water suspension has been tried to aid in photolysis studies. However, UV radiation will not penetrate deeply into solids, so that adsorbed PCB must be kept close to the surface.

2.2.2.3 Experimental Factors in UV-Assisted Ozone Oxidation of PCBs

For several decades the advantages of ultraviolet radiation in the sterilization of aqueous and dry media have been known. Likewise, the powerful oxidizing effects of ozone, which produce sterilization, have been known. It is only with the relatively recent advent of requirements for removing refractory organics from water, and the ability to detect these organics in parts per trillion and even lower concentrations, that the pressing need for more powerful oxidizing capability has been felt. It was quite natural to combine the two effects into a single or staged treatments. It has been found that there is a strong synergism in many cases.

Enough data is now accumulating to show that this category of wastewater treatment is a powerful method for removal of refractory organics from water. It has the potential of removing organics to an effective zero discharge level. However, as the removal of very small concentrations becomes exponential with time, the residence time required in UV-ozone treatment equipment becomes a critical factor. The following variables have been identified as affecting residence time:

- Molecular structure of the organic
- Concentration
- UV transmissivity of the wastewater
- UV intensity

- UV wavelength
- Ozone concentration
- Liquid turbulence and gas-liquid contact (transfer coefficients)
- pH
- Temperature

The following sub-sections will present experimental findings about the importance of these variables.

2.2.2.4 Destruction of PCBs and Refractory Organics at Houston Research, Inc.

2.2.2.4.1 PCBs Destruction Data

In preliminary experimentation to show feasibility of PCBs destruction, a high pressure 650 watt mercury tube generating 2537 Angstrom radiation was used in a 21 liter reactor. Figure 2.2.2.4.1-1 shows the arrangement for a smaller reactor. Oxygen was sparged in at 3 liters per minute, with an ozone concentration of 2%. This was felt to be excess ozone usage, but a good starting point for tests. A 1000 ppm solution of Aroclor 1254 in methanol was used to get a 514 ppb solution of Aroclor 1254 in water. Otherwise the solubility of Aroclor 1254, which is about 50% pentachlorobiphenyl, is only 12 ppb in water. It was theorized that significant destruction of this compound would forecast even greater destruction of the other Aroclors now produced, which are all less chlorinated and more soluble in water.

Figure 2.2.2.4.1-2 is a plot of the normalized residual concentration of Aroclor versus time of UV-assisted ozonation. It can be seen that in one hour about 2/3 of the PCBs had been decomposed; and in three hours, only about 7 percent of the original PCBs remained.

2.2.2.4.2 Operating Data Obtained from Refractory Organics Tests

During the past four years work has progressed at Houston Research on ozonation for water purification. Comparison tests have shown that the addition of UV radiation enhances the reaction rate

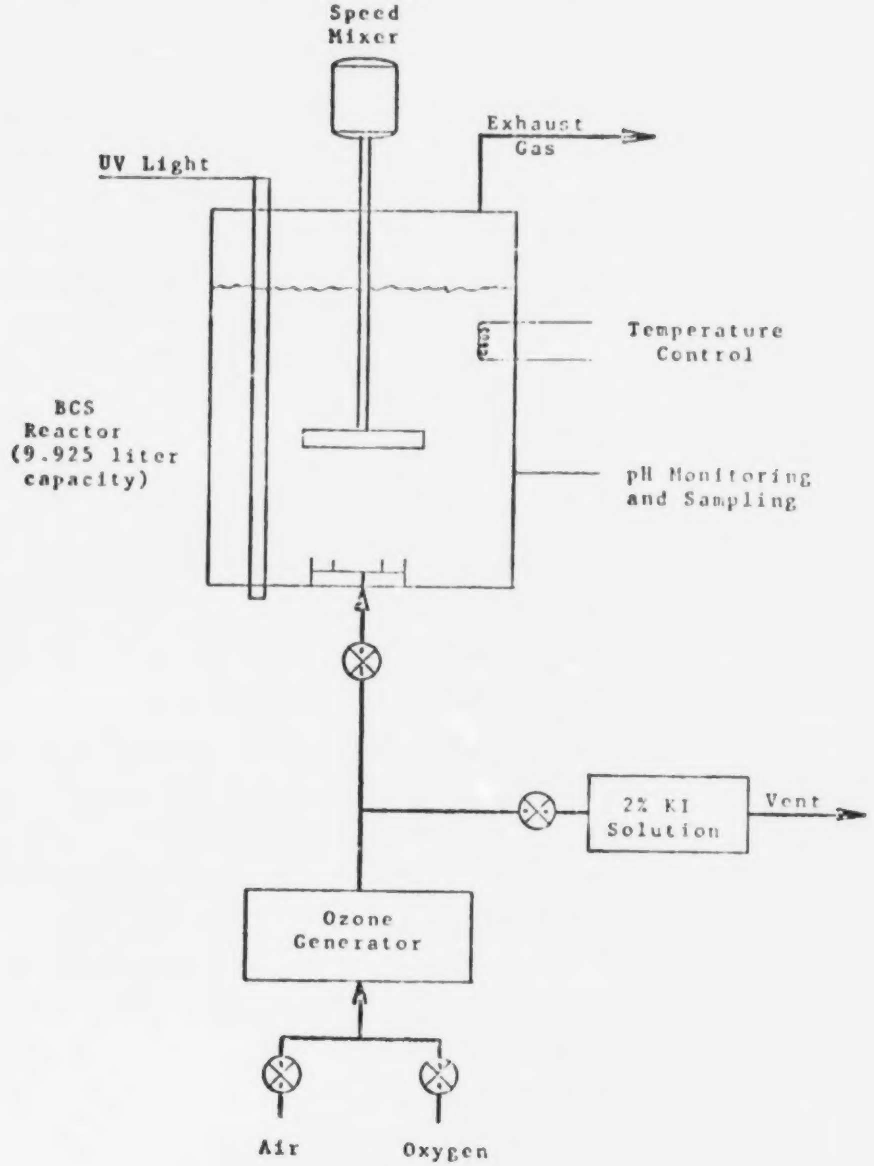

Variable Speed Mixer
UV Light
Exhaust Gas
Temperature Control
BCS Reactor (9.925 liter capacity)
pH Monitoring and Sampling
2% KI Solution
Vent
Ozone Generator
Air
Oxygen

Figure 2.2.2.4.1-1. Lab Scale Apparatus for Reaction and Mass Transfer Studies at Houston Research, Inc.

for the destruction of organics by 10 to 100 fold. Further it was found that, for the most refractory compound they had tested prior to the PCBs, acetic acid, there was essentially no reaction without UV assistance. However, with UV radiation, the oxidation proceeds rapidly at room temperature.

Figure 2.2.2.4.2-1 shows the effects of UV and temperature on acetic acid destruction. The ordinate is the fraction of total organic carbon remaining, showing that for the 30°C or 50°C tests, with UV, there is nearly complete destruction in four to five hours to CO_2 and water. The fact that the curves are displaced to the right of the mass transfer limiting line shows that some chemical reaction rate improvement can be sought.

Figure 2.2.2.4.2-2 shows the oxidation improvement achieved by doubling the UV power input, with near constant temperature.

Further description may be found in: "Ozone/UV Process Effective Wastewater Treatment", by Prengle, Mauk, Legan and Hewes; Hydrocarbon Processing, October 1975, 82-87.

These are a sampling of the kinds of optimization experiments that must be run with the PCBs oxidation system to obtain good economy of design and efficiency of operation.

2.2.2.5 Destruction of PCBs and Refractory Organics at Westgate Research Corp.

2.2.2.5.1 PCBs Destruction Data

Cooperative testing and research between Versar Inc. and Westgate Research, Inc. was performed to determine the effectiveness of Westgate's UV-assisted ozonation process in destroying PCBs

The following experimental conditions were used in the treatment of synthetic wastewaters containing Aroclor 1254 and Aroclor 1016:

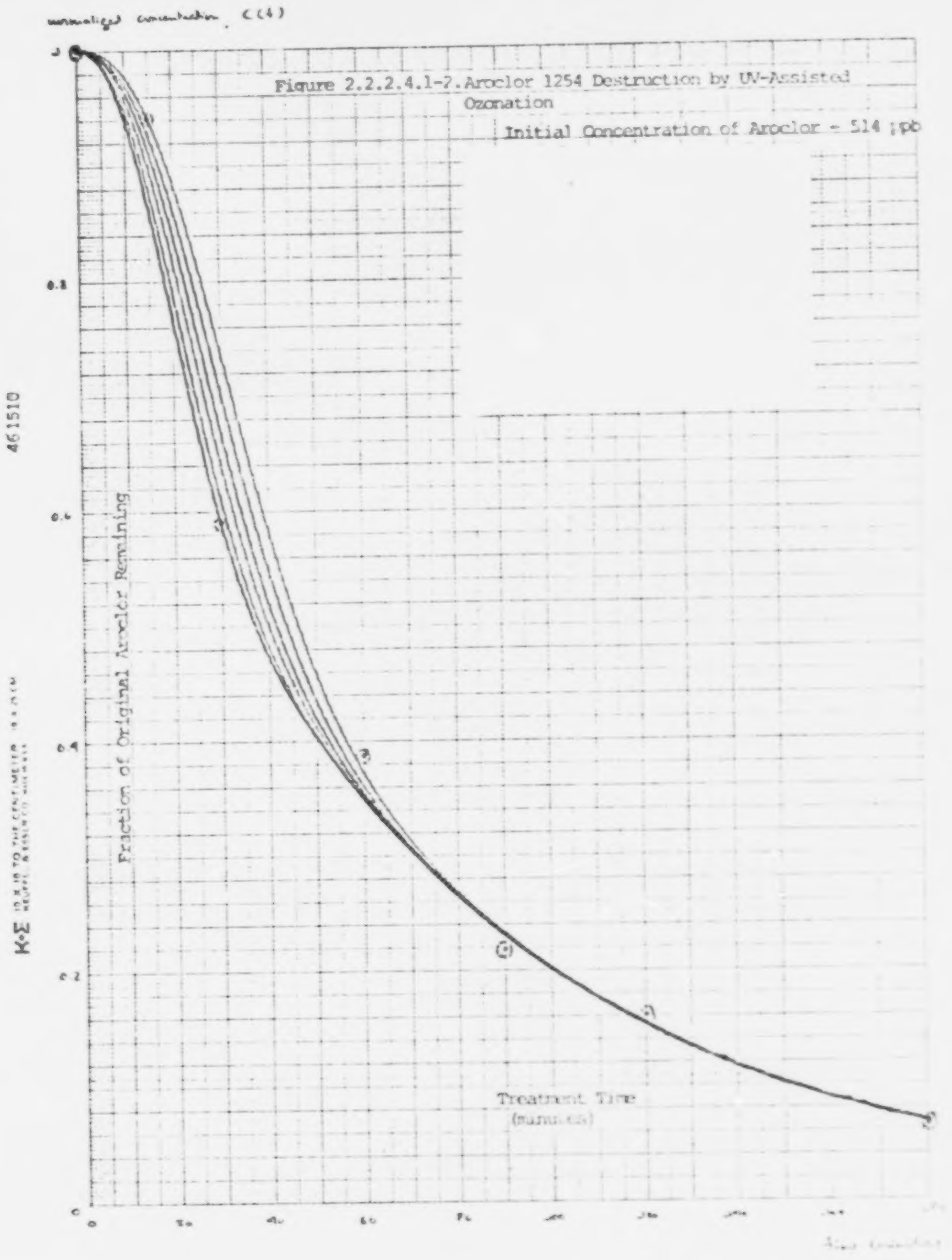


Figure 2.2.2.4.1-2. Aroclor 1254 Destruction by UV-Assisted Ozonation

Initial Concentration of Aroclor = 514 ppb

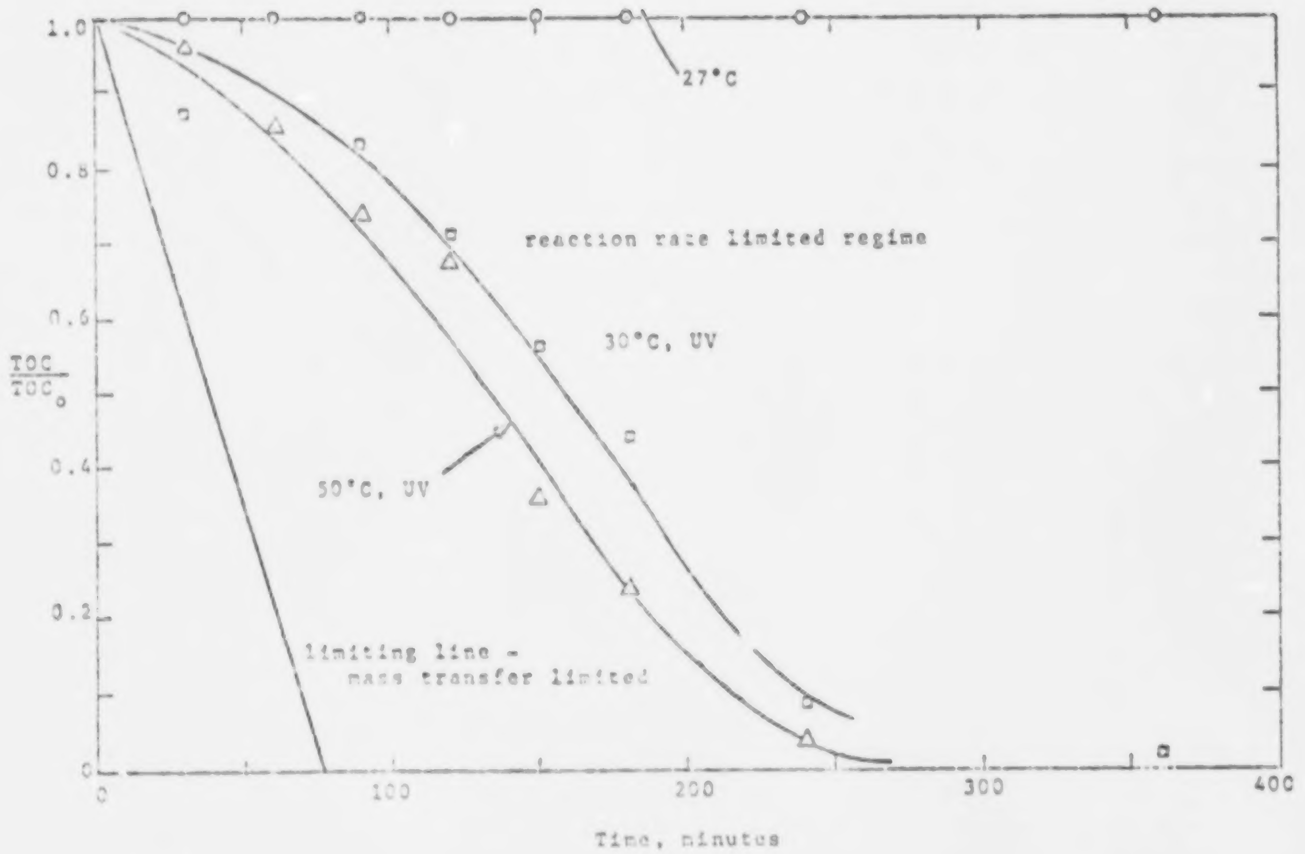


Figure 2.2.2.4.2-1. Ozone Oxidation of Acetic Acid, Effect of UV and Temperature [Initial CH_3COOH = 105 mg/l, $O_3(\ell)$ = 3.5 mg/l]

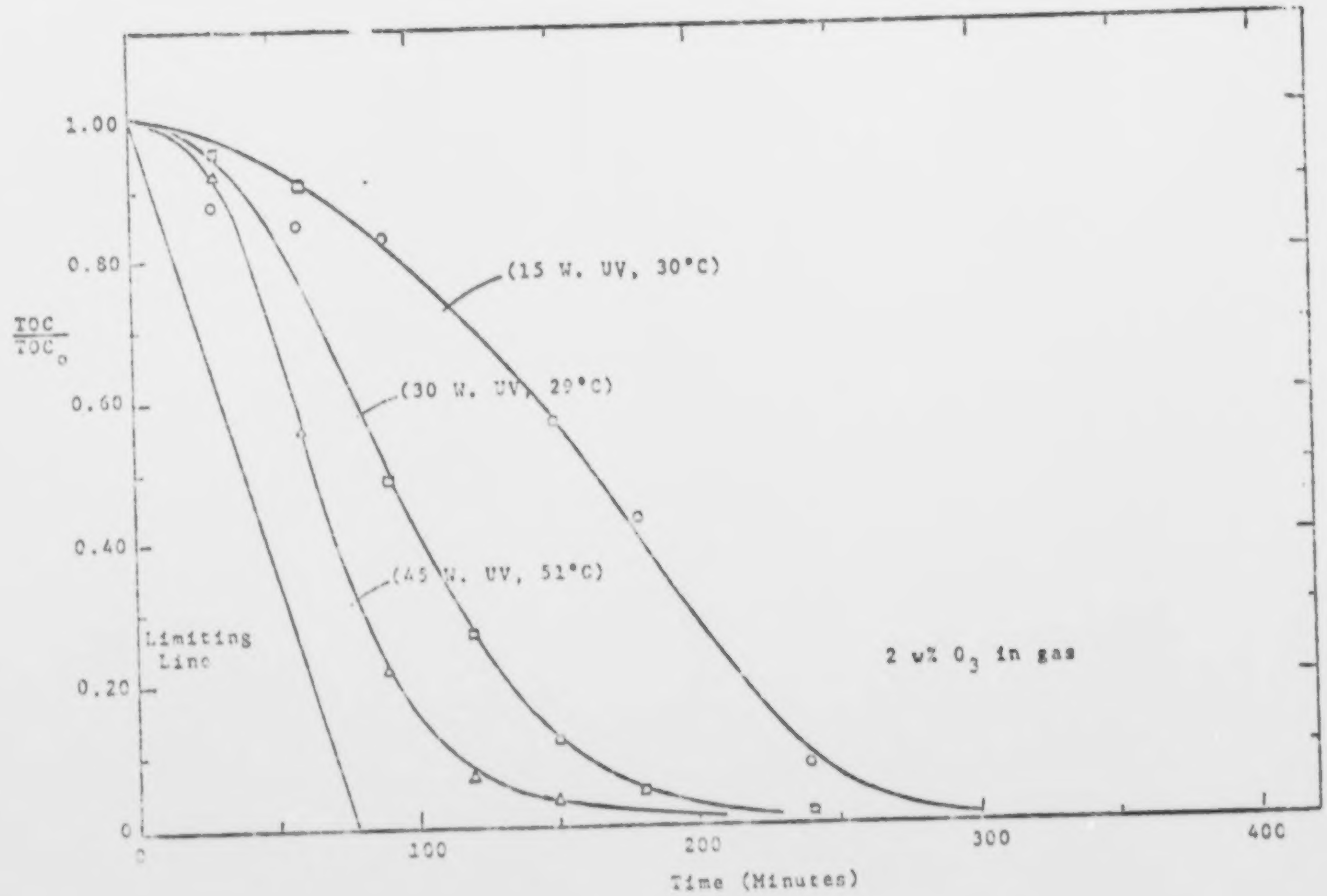


Figure 2.2.2.4.2-2. Ozone/UV Oxidation of Acetic Acid; Effect of Increased Radiation Input

Reactor volume = 3 liters

Reaction time = 4 hours (excess time used to give best chance of destruction)

UV Source = one 43 watt, low pressure Hg lamp operating at 2537 Angstroms

Reactor type = vertical, cylindrical, 18" long, 3" diameter (1½ UV path length)

Pressure = atmospheric

Temperature = 23°C

pH = 5.2

Ozone feed = 70 milligrams ozone/minute in 3.4 liters per minute of oxygen; or about 1.4% by weight ozone in oxygen

Reactant preparation = The pure PCBs (Aroclor 1254, were mixed with an equal proportion of methanol, and then with distilled water to get an apparent true solution. A Hamilton syringe, with vernier calibration to deliver down to a microliter, was used to prepare an estimated 200 ppb concentration in a beaker. This solution was added to the reactor (3 liters). Then a 200 ml sample was withdrawn to get the "before" sample.

When preparing the Aroclor 1016 solution, a more concentrated PCBs solution of about 800 ppb was achieved.

The before and after treatment concentrations of PCBs are shown in Table 2.2.2.5.1-1.

Table 2.2.2.5.1-1

UV Ozonolysis Destruction of Typical Capacitor and Transformer PCBs at Westgate Research

	Aroclor 1016	Aroclor 1254
Initial (influent) Concentration (ppb)	790	200
Final (effluent) Concentration (ppb)	0.5	1.5

Table 2.2.2.5.1-2

Destruction of Aroclor 1016 by UV-ozonation at Westgate Research

UV-Ozonation Time (minutes)	Aroclor 1016 Conc. (ppb)	Chlorinated Products Conc. (ppb)
0	237.0	0.00
15	14.7	33.8
30	7.76	25.86
45	1.73	21.80
60	1.73	18.47
75	0.52	17.63
90	5.2	21.43
120	<0.1	12.64
150	<0.1	16.91
180	<0.1	9.12
210	<0.1	23.07
240	<0.1	12.58

The data show that the destruction was highly effective in these pioneering tests; over 99% of the original PCBs were destroyed. In addition, the final concentration was at the desired level of about 1 ppb. Such an effluent would be expected to be a reasonable stream for recycle operations and intermediate term zero discharge potential.

Of course the contact time and ozone expenditure were overly large, but the goal of this preliminary testing was to demonstrate destruction of two key Aroclors in use today.

A more comprehensive study of the UV-ozonolysis of Aroclor 1016 was run, with samples removed from the reactor every 15 or 30 minutes for up to 4 hours. As shown in Table 2.2.2.5.1-2, the initial PCBs concentration was 237 ppb. Within 45 minutes the PCBs level had been degraded to 1 to 2 ppb, a 99^{+} percent decomposition. By two hours the PCBs concentration was less than 100 ppt (parts per trillion). The last column in the Table labeled "Chlorinated Products Concentration" is of particular interest. This is the first time quantitative data on the residual compounds in the reaction mixture have been compiled. These residual compounds occur at 33.8 ppb level within 15 minutes from the start of the test and then erratically and slowly drop in level to about 10 to 20 ppb over the four hour period.

The only statements that can be made about these residual compounds is that they are non-PCBs but chlorinated materials. Possibly an altered UV wavelength, or ozone concentration, or use of catalyst or other agent could degrade these other products to the non-detectable level. However, further testing is required.

2.2.2.5.2 Pilot Scale Tests of Refractory Organics Decomposition

In a paper presented at the 68th annual meeting of the AIChE, November 20, 1975; "UV-OX (TM) Process for the Effective Removal of Organics in Waste Waters", Zeff has described pilot scale tests of UV-assisted ozonation using 2537 Angstrom radiation. This work has grown from a patented invention for a household appliance to purify tap water. The effectiveness of the method is demonstrated by the reduction in TOC of 500 ml, of tap water from 5 mg/l to 1 mg/l in one minute, using 0.07 mg of ozone and 0.1 watts of 253.7 nm UV. The bacteria plate count was also reduced by a significant amount.

In these studies, batch reaction conditions were optimized to get closest to complete TOC destruction with least UV energy input and best O_3 use. Then continuous and two stage operations were investigated. As shown in Figure 2.2.2.5.2-3, a six inch path length of UV was compared with a three inch path. In a batch test, the longer path condition took 3 to 4 times as long as the shorter path to achieve the same TOC reduction, in approximate accord with the inverse square law of intensity reduction.

The laboratory scale equipment arrangement is shown in Figure 2.2.2.5.2-2. Table 2.2.2.5.2-1 presents TOC reductions for a 5 part organic mixture under two experimental conditions, showing ozone usage efficiencies, and energy usage efficiencies, with a simulated two stage continuous operation. Zeff has calculated the prime energy costs for UV assisted ozonation based on a scaleup of a pilot reactor. The pilot reactor handled 20 gph, so that 210 of these units in parallel would handle 100,000 gpd. The plant area needed for this equipment would be only 18 feet square, with a height of 3 feet.

Based on pilot tests of this reactor, it might be assumed that it could convert wastewater of 40 mg/liter of TOC to less than 5 mg/liter, using six-43 watt UV lamps. It is assumed that a UV energy requirement of 5 watt-minutes per milligram of carbon oxidized will suffice. Also, the ozone requirement will be 2 moles per gram-atom of carbon oxidized, but at a 75% efficiency, or 2/.75 = 2.67 moles ozone per gram-atom of carbon. Assuming a power cost of 1.5¢/KWH; the ozone generating power cost would be $53.40 and the UV power would be $18.93; or a total of $72.33 per 100,000 gal. of water treated.

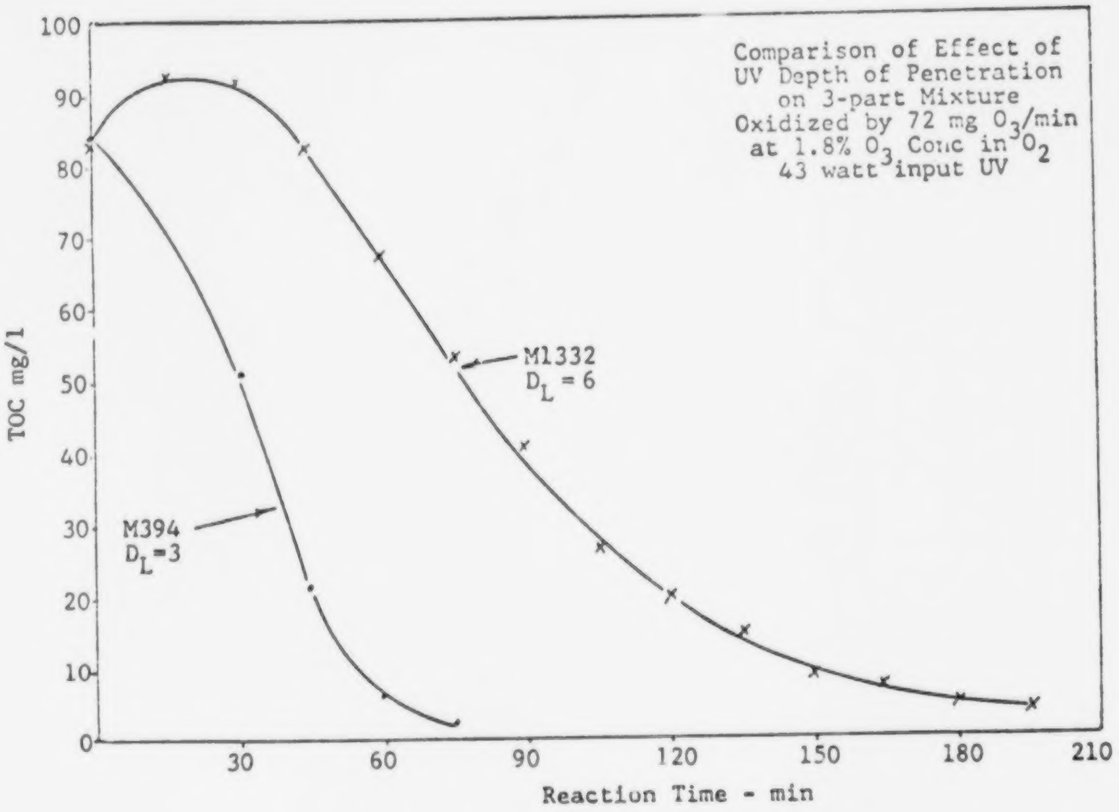


Figure 2.2.2.5.2-1

THE EFFECT OF UV PATH LENGTH ON TOC DESTRUCTION

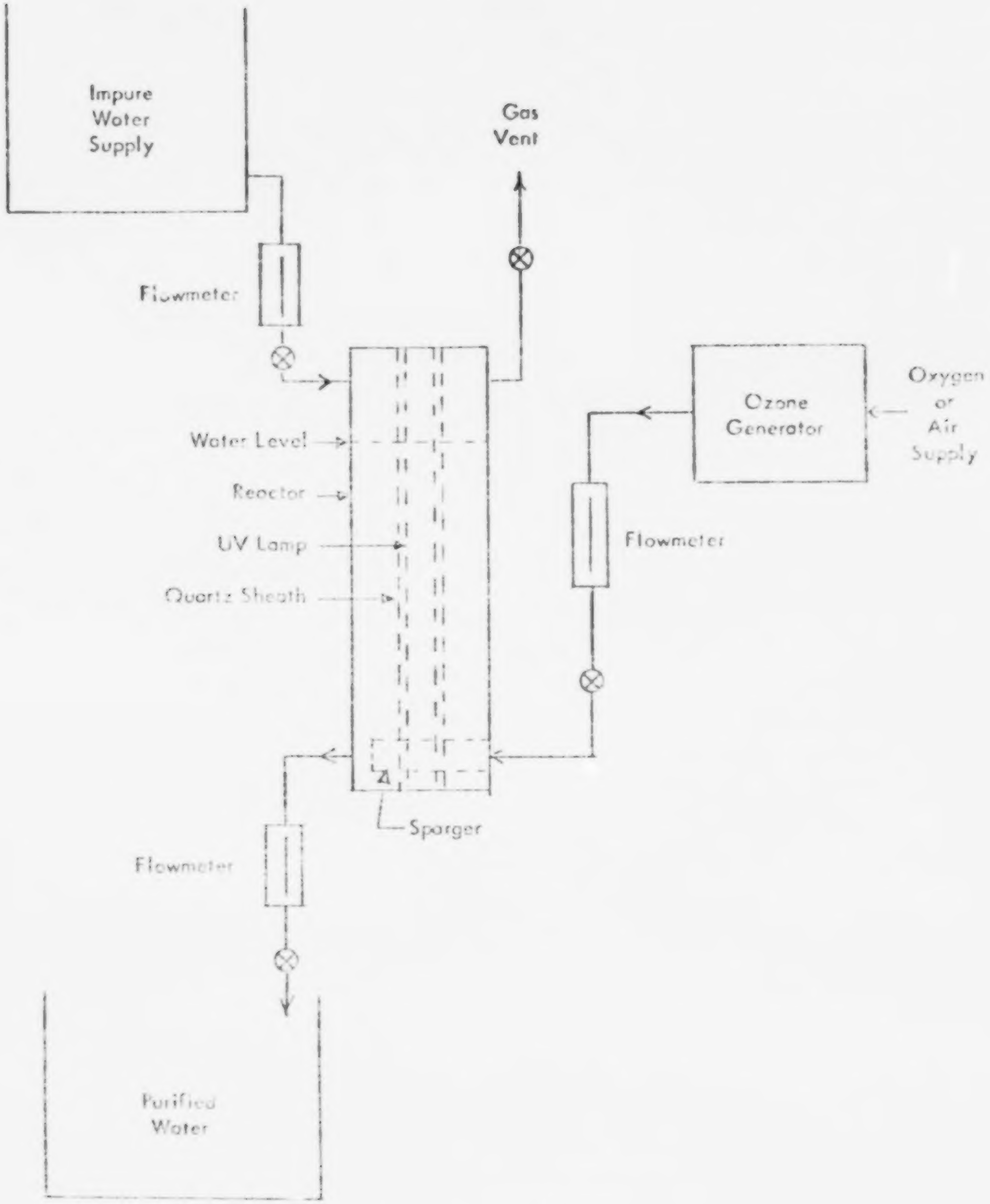

Impure Water Supply
Gas Vent
Flowmeter
Oxygen or Air Supply
Ozone Generator
Water Level
Reactor
UV Lamp
Quartz Sheath
Flowmeter
Sparger
Flowmeter
Purified Water

Figure 2.2.2.5.2-2
SCHEMATIC OF BENCH REACTION SYSTEM AT WESTGATE RESEARCH CORP.

	REACTOR 1										REACTOR 2								OVERALL		
Experiment Number	Influent Conc TOC mg/l	Res Time/Real min	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC Conc mg/l	Ave Rate of TOC Removal mg/min	UV Index w-m/mgC	Supplied TOC/O_3 Effic %	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC Conc mg/l	Ave Rate of TOC Removal mg/min	UV Index w-m/mgC	Supplied TOC/O_3 Effic %	Ave Rate of TOC Removal mg/min	UV Index w-m/mgC	Supplied TOC/O_3 Effic %
S341	39.0	80	2.5	124	1.3	65	9.0	4.5	9.6	29.0	2.5	124	1.5	74	5.0	0.6	46.7	3.9	2.5	13.9	16.4
S342	75.5	48	2.7	171	1.8	113	21.0	13.6	3.2	63.7	2.7	171	1.9	120	6.0	3.7	7.5	17.5	8.7	4.1	40.6

TABLE 2.2.2.5.2-3

Simulated Two-Stage, Continuous UV-Ozonation of a 5 Component Mix at Westgate Research Corp.

(43 watt UV Input Reactor 1)
(28 watt UV Input Reactor 2)

Zeff points out that the 210 reactor modules would require 1260 of the 43 watt lamps, at 6 per reactor. This appears to be a large number of lamps, but it is actually very practical. Such arrays of lamps are regularly used for room illumination in factories and large offices, and the low-pressure mercury lamps used here are nothing but fluorescent lamps without the phosphor coating. An extended array such as this is much more energy-efficient than fewer high-power, high-pressure, "industrial" UV irradiators; and maintenance and replacement of lamps is much simpler. The life of the low-power lamps is 7500 hours as compared to 1000 hours for the high-power lamps.

2.2.2.6 Laboratory Test Results from AiResearch Corp.

In these tests, high pressure 450-watt mercury lamps were used. The test solutions were very dilute mixtures of methanol, ethanol, isopropanol, and acetone in water. The ozone was introduced into the 1 liter organic mixture in an oxygen stream, that was bubbled in at 2 liters per minute, at an ozone concentration of 33 mg/liter. With the expenditure of 7.9 grams of ozone, the mixture of alcohols and a ketone was reduced from 115 mg/l COD to 10 mg/l in 2 hours.

2.2.2.7 Comments on UV-ozone tests

These highly encouraging test results by three different companies in the destruction of some of the most refractory organics encountered in wastewater treatment, give confidence that scaled-up systems could adequately destroy PCBs in industrial wastewaters. The next step required is detailed cost effectiveness testing in pilot scale equipment.

2.2.3 Non-Carbon Adsorbents for PCBs

A variety of non-carbon materials, some well known for treating water, and some that seem to be quite specific for PCBs removal have been found. Limited cooperative laboratory testing of PCBs removal has been conducted in order to gain an insight into potential effectiveness.

Materials considered or examined were:

1) Rohm and Haas Amberlite AD series resins. These were laboratory-tested for PCBs removal.

2) Polyvinyl chloride. This was tested by Canadian investigators for PCBs removal.

3) Clays and Humus. These were tested by Monsanto for PCB removal.

4) Polyurethane. This was tested by Canadian, Swedish and other investigators for PCB's removal.

5) Sphagnum Peat. This is used in commercial water purification, but has not been tried with PCBs.

6) Polyelectrolytes as flocking agents. These are not really adsorbents, but could be aids to removing finely divided adsorbents from treated wastewaters. They were not tested.

7) Coal. This was not tested with PCBs, but is being experimentally used for water treatment.

8) Molecular Sieves. These were not tried with PCBs, since they were judged to be of improper character. They would be expected to preferentially remove water from PCBs.

9) Miscellaneous Sorbents. There are a number of proprietary Oil Sorbents, such as the "3M Brand" series, that were not checked with PCBs, but might have some application.

2.2.3.1 The Amberlite XAD Series of Macroreticular Resins

2.2.3.1.1 PCBs Adsorption Testing

Cooperative preliminary experimental work was carried out between Versar and Rohm and Haas to test the PCBs adsorption capacity of XAD-4 resins. New data was provided which confirmed the effectiveness of this resin, which had been previously shown by Lawrence (as described in Appendix D of this report).

Since carbon adsorption is the more established technology for removal of organics, it was felt that a side-by-side comparison of a carbon and an Amberlite(R) resin would add valuable information.

These tests showed that the resin and the carbon have comparable effectiveness in PCBs removal. The resin method envisions on-site regeneration with the concentrated waste PCBs treated by incineration.

Details on the apparatus and materials used by Rohm and Haas and the results of their experiments are given in Appendix B.

2.2.3.1.2 Process Concept for Resin Adsorption of PCBs

Based upon the experiments described in Appendix B and the general Rohm and Haas experience with removal of organics from wastewater, they have envisioned the following as a workable plant scale process, subject to further experimentation. The wastewater to be treated is passed through one or more columns, each containing polymeric adsorbent. Once the resin is loaded to capacity with PCB, it is taken off line for regeneration.

A water miscible solvent is usually used for regeneration, and is in turn displaced from the adsorbent by water. The stream resulting from this operation is carefully fractionated to optimize solvent recovery. The final rinse usually contains a very low level of solvent in water and this must be collected as a PCBs wastewater.

The distillation column permits solvent recovery at high purity, leaving water and PCB in the bottoms from the column. To minimize distillation costs, a patented variation of the process, called "superloading", is used to maintain a high PCB concentration in the final toxic material to be disposed. Part of this process is illustrated as a separator from which the organic phase is PCB while the aqueous phase is recycled to "superload" the AMBERLITE adsorbent. A completely enclosed system can readily be designed to insure minimum operator exposure to PCB.

A process concept flow sheet of PCB removal system is shown in Figure 2.2.3.1.2-1.

The experimental work recommended so that this concept may be moved to plant design stages is as follows:

1. More extensive leakage data should be gathered for XAD-4 and other AMBERLITE polymeric adsorbents, encompassing several influent concentrations of PCBs. Other Aroclors should also be tested.

2. The ability of the AMBERLITE polymeric adsorbents to be solvent regenerated should be demonstrated and the optimum solvent determined.

3. The capacity of the AMBERLITE polymeric adsorbents should be determined over a number of loading/regeneration cycles to see the effect, if any, of long term operation on capacity.

The description of XAD-4 resin and its comparison with other Rohm and Haas resins, which also might have application to PCBs removal, are given in Appendix C.

Further descriptions of non-carbon adsorbents are presented in the Appendix D. They contain relevant experimental work on PCBs and refractory organics, and are included to give a more complete picture of the options assessed under this program. Also included in Appendix D is summaries of catalytic reduction, catalytic oxidation, microorganisms studies, and ultrafiltration and reverse osmosis. For the removal of PCBs from wastewater, these are all considered to be in the research stages. Several of them may have potential for contributing to zero discharge technology.

2.3 Treatment of PCBs - Contaminated Solid Wastes

2.3.1 Incineration

This technology has already been best described under subsection 1.3.3. For the variety of solids ranging from granular particulate like fuller's earth, to large chunks of solids, like tranformer internals, all

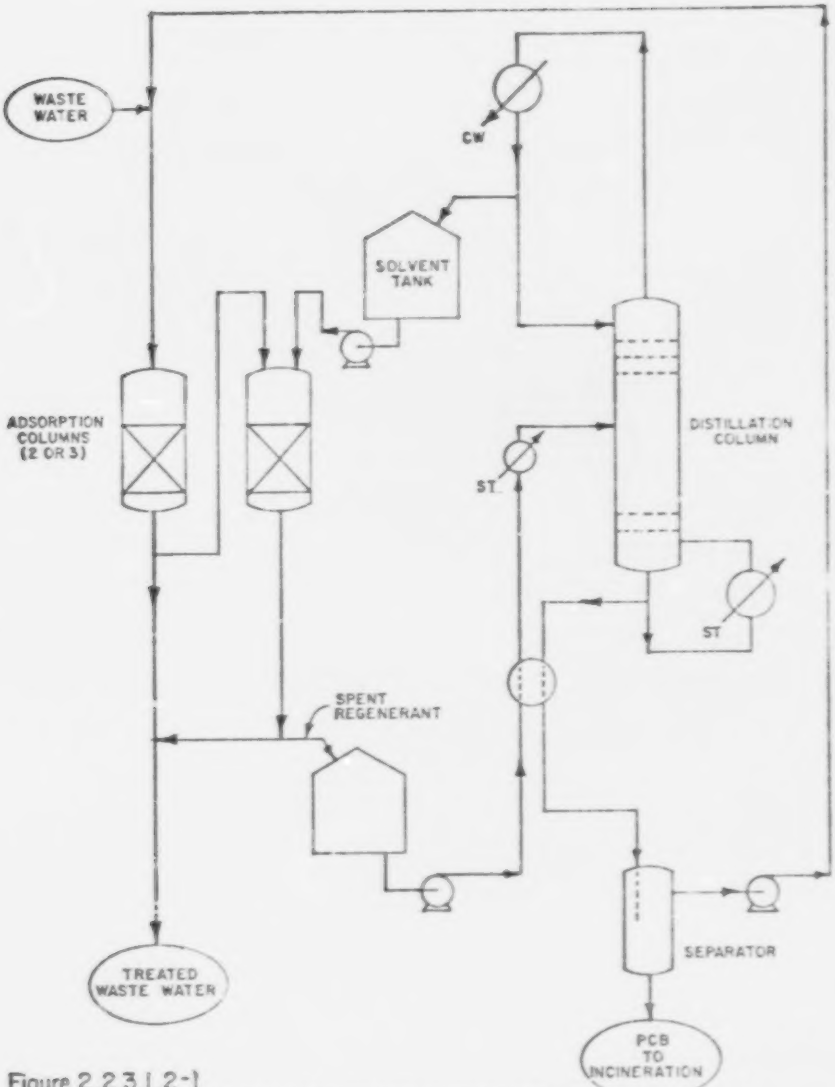

WASTE WATER
CW
SOLVENT TANK
ADSORPTION COLUMNS (2 OR 3)
DISTILLATION COLUMN
ST.
ST
SPENT REGENERANT
SEPARATOR
TREATED WASTE WATER
PCB TO INCINERATION

Figure 2.2.3.1.2-1
PROCESS CONCEPT FLOW SHEET FOR PCB's REMOVAL
BY ROHM AND HAAS COMPANY

impregnated with PCBs, the best destruction method is a rotary kiln. This should be followed with adequate afterburning to prevent PCBs vaporization.

2.3.2 Sanitary Landfill

The best technology for segregation of the PCBs solid wastes so that spillage, leakage to waterways, or emissions to the atmosphere will not occur, is described under section 1.3.3.

2.4 Treatment of Air Emissions

2.4.1 Condensation Methods

Our plant survey showed at least one location that was practicing chilling of exhaust gases from PCBs processing areas. With the low vapor pressure of PCBs even at room temperature, it might be expected that they could be effectively swept out of chilled air with the condensing water. Undoubtably this does occur to some extent; however, the high activity coefficients of PCBs would tend to keep the PCBs vaporized at a level somewhere near their pure liquid vapor pressure at that low temperature. Previous work by Versar has shown that PCBs in stack emissions from sludge incineration are not removed by water scrubbing (EPA Contract 68-01-1587).

2.4.2 Granular Adsorption Methods

Although no data was found for collection of PCBs from an air stream by any form of granular filter, it would be expected that such treatment would be effective. In fact, it would be expected that the same adsorbents discussed under 2.2.1 and 2.2.3 above would be the most effective. Activated carbon removal of organic vapors has been practiced in such widely divergent circumstances and devices as gas masks, kitchen range hood systems, and submarine air recycle systems.

2.4.3 Catalytic Oxidation of Organics in Evaporated Effluents

The following studies of vapor phase oxidation seem to offer a potential for PCBs destruction in air exhausts at much lower temperatures than incineration levels. Catalysts would have to be resistant to HCl vapors, but fuel savings and insulation savings would be large. It appears that this procedure would be amenable to all proportions of water and organics in such air streams.

Borkowski ("The Catalytic Oxidation of Phenols and other Impurities in Evaporated Effluents," Water Research 1 367 (1967) passed the vapors over a catalyst at elevated temperatures. Copper oxide was the most active of a large number of catalysts tested and oxidation appeared to be complete to carbon dioxide and water at temperatures over 300°C and a residence time of about 0.08 seconds. Without the catalyst 1000-1200°C was required to achieve the same degree of removal.

Walsh and Katzer ("Catalytic Oxidation of Phenol in Dilute Concentration in Air", Ind. Eng. Chem. Process Design Develop. 12 477 (1973)) studied contaminated air-water vapor streams over supported copper oxide and showed that the rate was first order in phenol and relatively rapid between 150 and 270°C. At 150°C and a space velocity of 4100 hr^{-1} the phenol conversion was 99.6%, and there was little evidence of any intermediate organics in the condensate.

Again, these methods of air purification are in the research stages, and actual testing of PCBs in air is required.

2.5 The Potential for Zero Discharge

The best method of achieving zero discharge, in the face of the practical problem of defining what is a zero concentration, is to establish total recycle. This appears feasible for wastewater, but not for solids or air emissions. Fortunately, for solids, we have incineration technology which promises very high efficiency of destruction simply by setting the temperature and residence times high enough.

For air emissions, although vapor pressures are low for PCBs, there is a potential for large surfaces giving off small quantities of PCBs. The research technology shows approaches to powerful adsorption and destruction methods for organics in air. If the latter can achieve destruction at lower temperatures through catalytic action, equivalent to that achieved by incineration, near zero emissions are predictable.

For wastewater recycle, the powerful methods of adsorption and catalytic destruction promise PCBs reduction to levels low enough such that reuse is practical. Our survey has shown some municipal and fresh waters have PCBs concentrations of one or more ppb; and river water can be many times that. Thus the recycled water at one or more ppb level of PCB would be very suitable for use.

3.0 RATIONALE AND SELECTION OF CURRENTLY RECOMMENDED WASTE TREATMENT METHODS

Based upon our plant surveys of the PCBs-using capacitor and transformer manufacturers, the PCBs manufacturer and the waste treatment equipment suppliers, and upon the analysis and evaluation of all available technologies whether in commercial use, pilot plant, or research states, we have developed recommendations for the most practical treatment methods to use now, and predictions of what could be applicable over the short and long term future. Our current recommendations are based heavily on technology that is currently in commercial scale use, and at the same time is doing an excellent job of PCBs destruction or removal, or else it holds great promise of doing that job based upon success in similar applications.

3.1 Incineration Recommended for Liquid PCBs and Scrap Oils

For this category, we determined only two candidate methods: incineration and sanitary landfill. It is possible that some of chemical degradation methods discussed under wastewater treatment might later become applicable to the concentrated PCBs liquid, but the prospect was not clear at this time.

Sanitary landfill is not recommended for liquids when incineration is available. The potential for liquids escaping in large quantities from ruptured containers, caused by any of a number of circumstances, and then causing massive leaching and liquid control problems at the landfill, is felt to be too great.

Incineration, on the other hand, offers a straightforward and physically simple method of final destruction. Incineration facilities that have successfully handled PCBs liquids are available in Massachusetts, New York, Delaware, Illinois, Texas and Louisiana. Other pilot or experimental facilities are available in other parts of the country. With the increase in requirements for disposing of many other liquid organics, it is expected that new facilities suitable for PCBs destruction will be added.

We therefore recommend incineration and particularly if there is a choice of the kind of disposal facility to erect at a new location.

3.2 Carbon Adsorption and UV-Assisted Ozonation Recommended for PCBs in Wastewater

Our survey of wastewater treatment technology was most extensive, and excellent potential for current, near and long term methods was found. The longer term pilot or research scale methods hold great promise of allowing zero discharge.

In this category, our prime recommendation is carbon adsorption. This technology has been proved over most of this century in a wide variety of industrial adsorption problems. It is being applied successfully to the removal of new organics from water on a continual basis. Our cooperative laboratory work with several suppliers has confirmed preliminary published reports of success in removing PCBs. All of the aspects of commercial carbon adsorption from favorable capital and operating economies to reasonable operating methods, materials of construction, and lack of transport of pollution to air or land, have been proven for PCBs-like materials. There is every reason to believe that there will be commercial success with PCBs removal from wastewater.

Potential disadvantages are the collection of backwash water and the spent carbon for incineration or other treatment. With these limitations in mind, a search was made for an alternate not having these limitations.

As an alternative, we recommend consideration of UV-ozonation. It is appreciated that this technology is still somewhere in the pilot plant to research stages. However, our cooperative testing with two equipment suppliers shows the method to be effective in destroying PCBs. It offers the potential of also degrading breakdown products all the way to CO_2, water [illegible] kind of a process, that generates no solids or liquids for later disposal, must be considered for application where no wastewater treatment of any kind now exists, and where facilities for incineration of carbon system wastes are not convenient.

The major factors yet to be determined for the UV-ozone systems are costs and operating practicality. Separately, UV and ozone systems are being used for commercial systems. It is therefore anticipated that the combination will be practical. Choices of the proper UV radiation wavelength and power levels still needs to be made; as well as methods of improving ozone use efficiency. It appears that commercial UV and ozone generators are suitable for this use.

3.3 Incineration and Landfill Recommended for Contaminated Solids

For PCBs contaminated solids, although incineration is recommended because of its final destruction capability and prevention of any long term problems, sanitary or scientifically controlled landfill must be considered a close second choice. At present, the only known facilities for handling a wide variety of solids are those of Rollins Environmental Services in Delaware, Texas and Louisiana. This limitation on locations for treatment requires that the alternate, landfill, be included.

Landfill, as practiced by Chemtrol Corp., appears perfectly suitable for containment of PCBs, at least over a medium term. Our reservation with this method is that it might be relegating a problem to the future. Our concern is that some decades in the future, when a landfill is closed for any reason, no agency will be prepared to handle the maintenance, sump emptying and the like to prevent leaching. We anticipate that some time in the future, many landfills will have to be mined, and final destruction or recovery made of the materials, for land use or hazard reasons.

3.4 [illegible] Carbon Filter Adsorption Recommended for Control of Air Emissions

[illegible] much the same reasons as in 3.2, above, we recommend that current emissions of [illegible] in plant air be trapped in carbon-containing filters. It is [illegible] newer and better adsorbents may emerge from research such as described in section 2.2.3, but it is felt that such advances will be readily applicable to any kind of filter pack, screen, cartridge or the like.

Carbon's long record for proven capability in this area is an overwhelming factor in its choice. There is the generation of contaminated carbon, and it must be incinerated or treated. For this reason, over the longer term, we see the use of low temperature catalytic oxidation methods as described in section 2.4.3. Those research methods hold the promise of near zero discharge, with the generation of no solid wastes.

SECTION VII

COST OF TREATMENT AND CONTROL TECHNOLOGIES

1.0 SUMMARY

The estimated maximum total annual cost for the treatment of all contaminated and potentially contaminated wastewater to a PCB concentration of 1 ppb or less, the incineration of scrap oils and the incineration of contaminated solid waste generated in the domestic production and utilization of polychlorinated biphenyls (PCBs) is $9,610,000. Expressed in other terms, this maximum total annual cost represents $0.28 per pound of PCB produced and utilized within the United States. The basic assumptions and rationale employed in developing this estimated maximum annual cost can be summarized as follows:

1. The raw water supply of the only domestic producer and all transformer and capacitor manufacturers is assumed to be contaminated with PCBs. In addition, the assumption is made that ultimate PCB discharge regulations will be based on gross PCB discharge and not on net additions. The basic assumption regarding the contamination of raw water supplies is believed justified on the basis of plant visits conducted during this study since raw water supplies were reported to contain from 1 to 57 parts per billion PCBs. The assumption regarding the ultimate development of PCB discharge regulations on a gross discharge basis is open to question, but is believed to be a reasonable assumption for the purposes of estimating maximum annual cost.

2. All runoff resulting from precipitation on the buildings and grounds of domestic PCB manufacturers and users will be contaminated with PCBs and will therefore require treatment prior to discharge. This assumption is based on two additional assumptions including (first) that historical use of PCBs has been relatively uncontrolled and that buildings and grounds can be assumed to be contaminated with PCBs, and (second) that all plants

regardless of age, employ local and general exhaust ventilation systems in PCB use areas and that PCBs are thereby redeposited continuously on the buildings and grounds from these ventilation systems. It is recognized that the potential exists for control of ventilation systems at the source through the application of adsorbant materials such as activated carbon. However, it is again believed that this assumption results in the worst case and thereby permits estimation of the maximum annual cost for PCB discharge control.

3. All non-contact cooling waters are contaminated based on assumption 1 and are employed on a once-through basis thereby requiring treatment prior to discharge.
4. All sanitary wastes, with the exception of waters employed for personal hygiene, are segregated and discharged to separate treatment facilities (the costs of which are not included in this estimate) or to municipal facilities.
5. All other process waters, condensates, boiler blowdowns, etc. are collected and subjected to treatment.
6. All waters derived from the sources described in items 1 through 5 are subjected to a treatment system comprising quiescent settling for settleable solids removal and free oil skimming, equalization, fine media filtration, carbon adsorption, flow measurement and sampling, and discharge to surface receiving waters. All sludges and free floating oils are disposed of through incineration. All backwash waters from the carbon adsorption system and fine media filtration are routed back to the gravity separation basin and thence through equalization, etc. All exhausted carbon is destroyed through incineration for waste flow up to 300 gpm (this assumption was made since it is not believed that existing commercial regeneration facilities are adequately equipped to permit complete destruction of PCBs employing

standard carbon regeneration practices). Above 300 gpm, specially designed on-site carbon regeneration is employed.

7. A flat fee of $.10 per pound has been assumed for the incineration of scrap oils and solid wastes contaminated with PCBs. This assumption is made on the basis of the maximum reported rate for incineration of such wastes at commercial waste disposal facilities.

1.1 Plant to Plant Cost Variations

The estimate of the total maximum costs anticipated for the manufacturer and users of PCBs was facilitated by preparing cost estimates for each plant site visited during the course of these studies and then aggregating to the total industry category on the basis of the percentage of the total industry represented by the visited plants. The total estimated cost was based on the assumptions listed under 1.0. This method of aggregating to the total industry is believed to provide a reasonable estimate of the total cost to be anticipated for the industry as a whole. However, other than for the plants actually visited, it is extremely difficult to make reasonable projections of the cost variations from plant to plant. The key variables affecting variation in cost from plant to plant are summarized and discussed below:

1. Most end-of-pipe treatment systems are significantly influenced with regard to size (and therefore cost) by the volumetric flow rate of the wastewater to be treated. In addition, in a case such as PCB contaminated wastewater, where the level of contamination is expected to be reasonably constant, the total treatment costs are essentially directly proportional to the volumetric flow rate. In reviewing the water usage rates at the plant sites visited during this study, it is apparent that the volumetric flow rate varies significantly from one plant to another with little apparent relationship between the production rate and volume of wastewaters. This situation results in a

considerable variation in cost from plant to plant for terminal wastewater treatment which virtually defies rational evaluation.

2. The extent of plant site contamination with PCB will impact on the quality and quantity of runoff water which will require treatment. It is anticipated, although difficult to quantify, that the extent of plant site contamination with PCB would be related to the plant age. However, it is conceivable that the extent of building and ground contamination with PCBs even in relatively new facilities could be rather high depending on the housekeeping control practices for handling spills, leaks, and otherwise contaminated materials.

3. Again, with regard to the volume of runoff water to be treated, the geographic location and terrain can influence this volume due to differences in level of precipitation and the local runoff coefficients.

4. It is believed that land availability will only be a significant factor when storm water runoff treatment is required. The principal land area requirement for the treatment facilities envisioned is in equalization and holding facilities which will be controlled by the quantity of runoff which must be captured and contained prior to treatment. In general, land availability and the cost of such land is too variable as to estimate. Of the plant sites actually visited, it is believed that most would have sufficient land available for all required treatment facilities. However, at least one plant was relatively congested and was in an area which was so highly developed that land availability could become a problem.

5. In the event that the raw water supply is not contaminated with PCBs, significant variations from plant to plant could

occur in the cost to effect segregation of non-contact cooling waters which could be directly discharged. Again, as previously indicated, of the plants actually visited, none reported that their raw water was contaminated by PCBs. However, it is possible that regulations could be developed on a net addition basis rather than gross discharge basis and therefore all plants might directly discharge non-contact cooling water without treatment.

1.2 Activated Carbon Terminal Treatment System

The actual PCB level attainable through activated carbon treatment is not well defined at this time. Theory would indicate that a zero PCB level could not be attained. However, it is quite conceivable that the effluent from a properly designed and operated carbon treatment system will be well below the analytically detectable limit (1 ppb) of PCBs. The rationale of selecting the activated carbon system for estimating the maximum total cost for waste treatment included the following considerations:

1. Although this system falls short of "zero discharge" in the sense of having absolutely no PCB discharge, it is believed quite probable that it would approach zero discharge from the point of view of being below the detectable limits.
2. Activated carbon adsorption is a field proven technology and the associated costs for construction and operation are well enough defined that industries or agencies reviewing the cost estimate could understand and have confidence in the cost data generated.
3. The only other potentially viable alternative, UV light assisted ozonation, has less well defined capabilities and is much more difficult to evaluate accurately for construction and operating costs.
4. Until such time as the exact capabilities of potential alternatives and the costs for these alternatives are accurately

known, it is believed that the activated carbon system would be installed in most cases. In any event, unless the UV/ozone system can do an equal or better job of destroying PCBs at a lower cost, it would not be selected by industry. Therefore, the costs estimated on the basis of an activated carbon system should represent the maximum anticipated costs.

1.3 Costs Based on Volume Flow

As previously indicated, the costs for the terminal treatment facilities considered herein are essentially proportional to the volumetric flow rate. The estimated total maximum annual cost for PCB wastewater treatment presented in this summary was based on "worst case" conditions. By developing all costs on the basis of volumetric flow, it is possible to examine the effect of removing certain wastewater categories from the total treatment requirement and evaluating the effect of this exclusion on the total treatment costs. In other words, if one desires to evaluate the reduction in costs which would be anticipated by assuming that storm water was not contaminated and that it could be directly discharged, one could remove this flow category from the total volume of wastewater to be treated and quickly evaluate the reduction in total treatment cost resulting from this change in assumptions. Several cases of this type have been examined in Section 3.6.

2.0 COST REFERENCES AND RATIONALE

This subsection summarizes and discusses the cost references and rationale employed in developing capital and operating cost estimates for the various control and treatment schemes presented in Section 3.0.

2.1 Interest Costs and Equity Financing Charges

For purposes of amortizing capital costs estimated in this section, an interest rate of 8% per annum has been assumed. The actual method of financing the construction of pollution control facilities are extremely varied and will undoubtedly differ from corporation to corporation. See Sections 2.3 and 2.6 for additional discussion of the amortization of capital costs.

2.2 Time Basis for Costs

All cost estimates contained in this report are based on first quarter 1976 dollars for both capital and operating costs.

2.3 Useful Service Life

The useful service life of major equipment items and treatment units projected for use in the treatment schemes presented herein may vary from 10 to 50 years. This assumes that the equipment is properly maintained and that it is employed for the service intended. However, it is believed that service life is of limited utility in this case since the long term use of PCBs is questionable. For purposes of amortizing capital costs, a payout period of ten years has been assumed in all cases. It is, of course, conceivable that certain equipment items such as stainless steel vessels could be salvaged at the conclusion of service for PCB contaminated wastewater treatment. However, it is not believed that the salvage value will be high enough to have any significant effect on the overall costs for construction and operation of the treatment systems.

2.4 Depreciation

Straight line depreciation was used over a ten year period.

2.5 Capital Costs

Capital costs as employed herein include the purchase price for major equipment and materials, delivery costs, installation costs, site piping, yard work and engineering fees associated with design and construction supervision. Capital costs do not include royalties or licensing fees which might be associated with any of the treatment systems which are under patent. Capital cost estimates do include reasonable profit and overhead for any contractors performing installation or construction services. Where possible, all capital costs for major equipment items have been based on vendor quotes for specific items of equipment. For items such as excavation and concrete construction, actual quantity estimates have been made and current unit costs have been employed.

2.6 Annual Capital Costs

All capital costs have been amortized over a period of ten years at 8% interest to define annual capital costs.

2.7 Land Costs

Land costs have not been included in any of the capital cost estimates. Except in rare instances where a production facility is actually "land locked" it is not believed that the cost of land would have a significant impact on the total treatment facility cost. A land area requirement curve has been developed to relate land area required to the volumetric flow of wastewater to be treated, see Figure 2.7-1.

2.8 Operating Expenses

Where available, curves relating labor requirements to various unit operations have been employed to estimate labor requirements. When such curves were not available for a specific unit operation, rational estimates of the operating labor requirements were made based on experience. All operating costs for labor have been estimated at $15 per manhour. Electric power costs have been estimated at $.02 per kilowatt hour. Commercial disposal of scrap oils, sludges and solid wastes have been estimated at $.10 per pound. Fuel costs have been estimated on a range from $1.00 to $2.00 per million BTU's depending on the use rate. (The exact value used is identified in each specific instance.) Costs for virgin activated carbon have been estimated at $.50 per pound.

2.9 Rationale for Incineration Costs

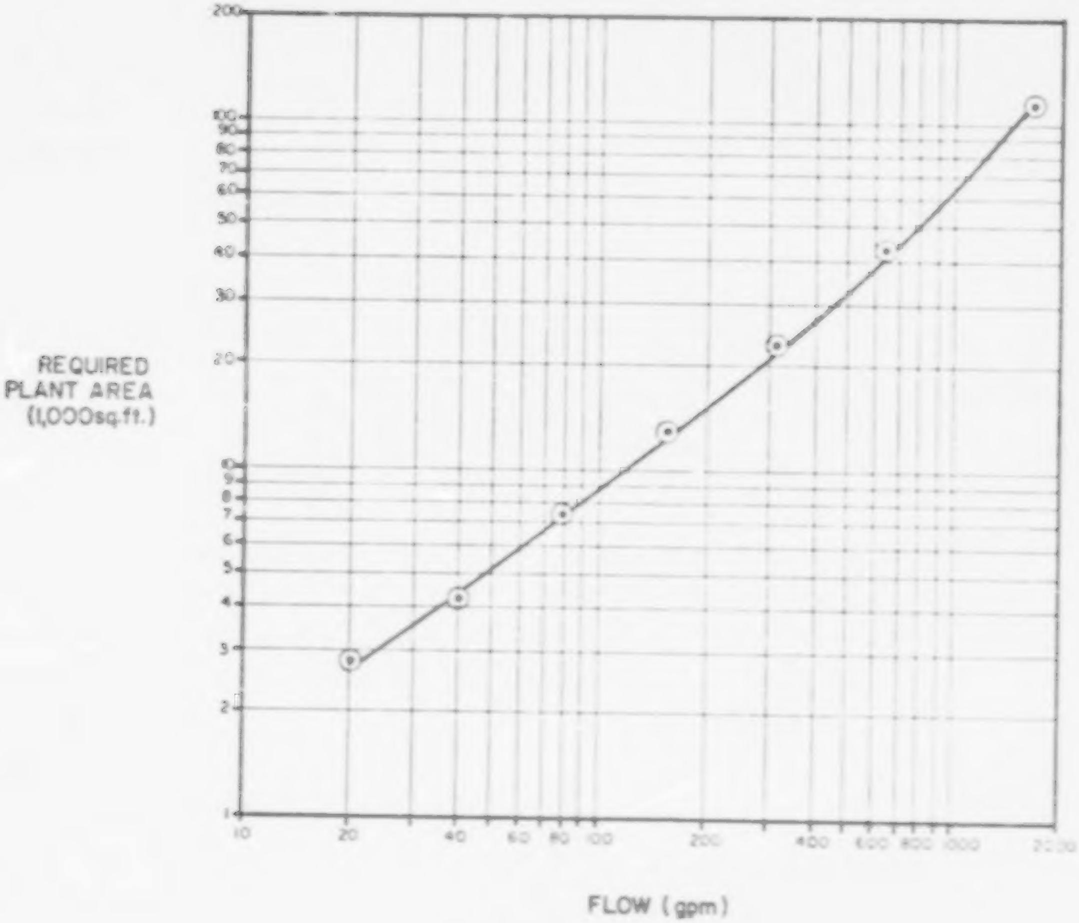
Incineration at a temperature of 2200°F for a residence time of 2-3 seconds has been identified as a means of completely destroying polychlorinated biphenyls. At the present time there are at least three distinct types of PCB contaminated wastes which are candidates for incineration. These include:

1) Pure organic streams, which are commonly referred to as "scrap oils". These may range from essentially pure PCB liquid to solvents with only low levels of PCB contamination.

2) Solid wastes which are contaminated with PCBs including reject electrical components, paper, rags, diatomaceous earth and clays used to filter PCBs, spent activated carbon, etc.

FIGURE 2.7-1

REQUIRED TREATMENT PLANT AREA FOR REMOVAL OF PCB FROM WASTEWATER



3) Aqueous waste streams containing from a few $\mu g/l$ PCBs up to tens of mg/l PCBs (only small quantities of this type material are currently incinerated, but this type of stream becomes very important in one of the proposed schemes for achieving "zero discharge". See Sections 2.11 and 3.3.3).

Of the producers and users of PCBs, only two, Monsanto and one transformer manufacturer, currently have on-site incineration facilities. The Monsanto facility for incineration is described in Section IV - 3.1.4. This system handles only organic wastes in the liquid form. The system capacity is approximately six million lb. per year.

The transformer manufacturer's incinerator also has a rated capacity of six million lbs. per year and is capable of accepting solid wastes such as transformer internals, paper, rags, and cardboard, but not diatomaceous earth, soil, etc. see Section IV, 3.3.1.5

In spite of the fact that these systems have only minor differences in configuration and essentially the same operating capacities, their present day estimated installed costs range from \$420,000 to \$1,100,000. The more costly system does include significantly greater storage capacity which may explain some of the cost difference. It should be further noted that both of these incineration systems were supplied by the same vendor. The point being made here is that there is no single representative system with a typical cost per unit of capacity.

In attempting to develop capital costs for incineration equipment, several leading suppliers were contacted. All suppliers were hesitant and virtually refused to provide guidelines for capital costs estimating unless very specific details of the system requirements were provided.

Since the design and fabrication of such equipment is a highly proprietary industry, it is believed that any attempt to estimate the cost of such systems on a rational basis would be fruitless. In addition, it seems quite improbable that the smaller capacitor and transformer manufacturing facilities would find it economically attractive or technically practical to install and operate incineration facilities for scrap oils and solid wastes contaminated with PCBs.

The alternative to on-site incineration is shipping scrap oils and solid wastes to commercial disposal firms. The handling practices and tolls associated with commercial disposal operations have been described in Section VI for both scrap oils and solid wastes. For purposes of estimation in this report, a flat rate of $0.10 per pound has been assumed for all scrap oils and solid wastes even if they are generated by facilities which have an on-site incinerator.

The off-site incineration of dilute aqueous streams in most cases may not be a feasible alternative basically due to the logistics and cost of transporting rather large volumes of water. In this case very rough estimates of capital costs for such incineration systems have been prepared and are presented in Section 3.3.3. In this case the accuracy of capital cost estimates are not deemed as critical since the operating costs, principally in terms of fuel consumed, are relatively high. It should be noted that large scale incineration of dilute aqueous streams is only considered as a portion of a proposed system to achieve "zero discharge" (see discussion in Section 2.10.2).

2.10 Definition of Levels of Treatment

2.10.1 Effect of Varying Effluent PCB Concentrations

At the inception of this study it was decided that treatment costs would be evaluated for effluent PCB levels of 1, 5 and 10 μg/l. Adsorbers using activated carbon may remove PCBs to concentrations less than one part per billion. An activated carbon system could be designed to obtain a choice of effluent concentration. However, it is very unlikely that such a design would produce a given level of PCBs on a continuous basis. The breakthrough of PCBs is anticipated to be relatively fast as compared to the actual run time of the adsorber; therefore, the operating cost savings for the various effluent PCB concentration are expected to be too small to justify designing carbon adsorbers for PCB removal at higher than one ppb levels. The costs for this system were evaluated at two influent COD levels, i.e., 30 and 50 mg/l.

For the second potential alternative, UV-ozonation, the work performed by Houston Research and Westgate Research indicates that the final concentration is a function of residence time and ultraviolet light catalyzed ozonation systems apparently can be designed to achieve any desired residual concentration of PCB.

For example, assuming the data can be extrapolated to very low PCB concentrations, the following information extrapolated from Houston Research data indicates the different residence times that could be involved.

Original Concentration, Co (ppb)	Final Concentration, C (ppb)	Residence Time, t (min)
500	10	260
500	5	310
500	1	420
200	10	200
200	5	250
200	1	360
50	10	110
50	5	160
50	1	270

These extrapolated data indicate that both residual concentration and final concentration dictate the residence time required. The data can be approximately represented by the equation

$$\ln C/0.9C_o = -0.01468 \ t$$

where:

C = final concentration, ppb
C_o = initial concentration, ppb
t = residence time, minutes

The actual test data may be seen in Section VI - 2.2.2.4. For this system, effluent PCB levels of 1 and 10 ug/l and influent COD levels of 30 and 50 mg/l were evaluated.

2.10.2 Zero Discharge Definition

Since the passage of Public Law 92-500, which establishes as a long term goal the achievement of "zero discharge" of wastes to the waters of the United States, the practical interpretation of the term "zero discharge" has been discussed and debated. The most stringent interpretation would be that of absolutely no discharge of either treated or untreated wastewaters. A second interpretation would allow discharge of treated wastewaters provided that contaminants in the wastewater were reduced to acceptable levels.

In the case of hazardous and toxic materials, the definition of the acceptable level of discharge is normally tied to the limits of detectability of analytical techniques available at that time. Unfortunately, this type of standard presents a moving target to dischargers since analytical techniques are continuously being improved.

In the case of PCB discharges being evaluated herein it is believed that treatment systems employing activated carbon and possibly UV catalyzed ozonation and polymeric adsorption could produce effluents which would be at or below the practicle limits of detectability for PCBs with currently available analytical techniques. However, since no full scale treatment systems are in operation at this time, this possibility cannot be confirmed.

For purposes of this study, zero discharge is evaluated for a system approaching the most stringent definition of zero discharge.

3.0 PCB WASTEWATER TREATMENT PLANT DESIGN PARAMETERS AND COSTS

3.1 Introduction

Any treatment system designed to remove PCBs from wastewater should be capable of handling all possible contaminated flows. These contaminated flows can include:

1. Rainwater runoff which washes PCBs from roofs and grounds.
2. Washdown water used to clean production areas where PCBs are used and manufactured items.
3. Washwater used for personal hygiene, but not toilet usage.
4. Water that has come into contact with air contaminated with PCBs, including cooling tower blowdown, steam jet ejectors, vacuum pump water seals and scrubber water.

With the exception of rainwater runoff, the volume of water is a function of the size of the production facility and attitude of labor and management toward water usage and/or conservation. These flows may or may not be relatively constant day to day. It is anticipated they will vary widely throughout the day. Rainwater runoff is a direct function of the location's rainfall and runoff area. The runoff area may or may not be dictated by the size of the production facility. This single flow would provide the largest flow variation for all production facilities. Since this variation exists, a flow equalization basin is necessary to provide a near constant flow to any downstream treatment unit operation.

Possible contaminants which have to be dealt with in any treatment system are:

1. PCB
2. Solvents - water miscible and immiscible
3. Detergents
4. Oils and other hexane soluble substances other than PCB
5. Suspended solids

All of these substances will be affected by their residence in an equalization basin. PCB present in quantities above about 200 ppb will separate from the wastewater and, unless acted upon by some other contaminant, settle to the bottom. Suspended oils and immiscible solvents will separate and rise to the surface. Suspended solids will either rise, fall or remain suspended depending on their densities and/or particle size. It has been found that suspended solids will absorb PCBs on their surface and these must be removed either in the equalization basin, a subsequent clarifier or by filtration. For the purpose of the design described in this section, it has been assumed that their concentration is low enough that they can be removed by separation in the first section of the separation basin and any remaining suspended material would be removed by multimedia filtration. If the solids are greater than 100 mg/l, a clarification system should be installed to relieve possible solids handling problems in the basin. A bar sreen or trash rake should be used to prevent large objects from entering the basin and creating problems with the downstream process feed pumps.

The wastewater is assumed to flow by gravity from its various sources to a point where it would be pumped into the equalization basin. Any heavy material collected from the bottom of the basin would be drummed and sent to an incinerator for decomposition of PCBs. The floating liquids would be removed by a belt skimmer and drummed for subsequent incineration, since these oils will contain high concentrations of PCBs. A schematic flow diagram for this treatment system is given in Figure 3.1-1.

The presence of water miscible solvents and detergents will most likely alter the level of PCB solubility in water depending on their concentration. There has been no comprehensive study to determine the affect these substances have on solubility due to the impossible number of contaminant systems that can exist. For the purpose of this report it will be assumed that PCBs will enter the equalization basin at an unknown concentration and leave it at 200 ppb and filtration will reduce the PCBs level to 50 ppb. Subsequent terminal treatment systems, i.e., carbon adsorption, UV-ozonation, etc. will reduce the 50 ppb PCB concentration to one ppb or less.

Any treatment design should incorporate unit operations that would completely contain PCBs and not allow them to enter the surface water. This requires a guarantee of the integrity of all drains, lines, pump stations and treatment operations.

The soluble substances which are not removed by filtration can be removed by a number of methods. Activated carbon adsorption and light catalyzed ozonation will be discussed in depth in this section. Due to the low effluent concentration required for PCBs, only those systems which can be purified by oxidation have been considered.

Activated carbon can be either incinerated or regenerated and the evolved PCB oxidized in a burn chamber at 2000° to 2200°F. This will insure that the treatment medium will not become contaminated to the point that it will be a significant source of PCBs to the environment. It should be noted that activated carbon adsorption systems are numerous and full scale operation has been documented.

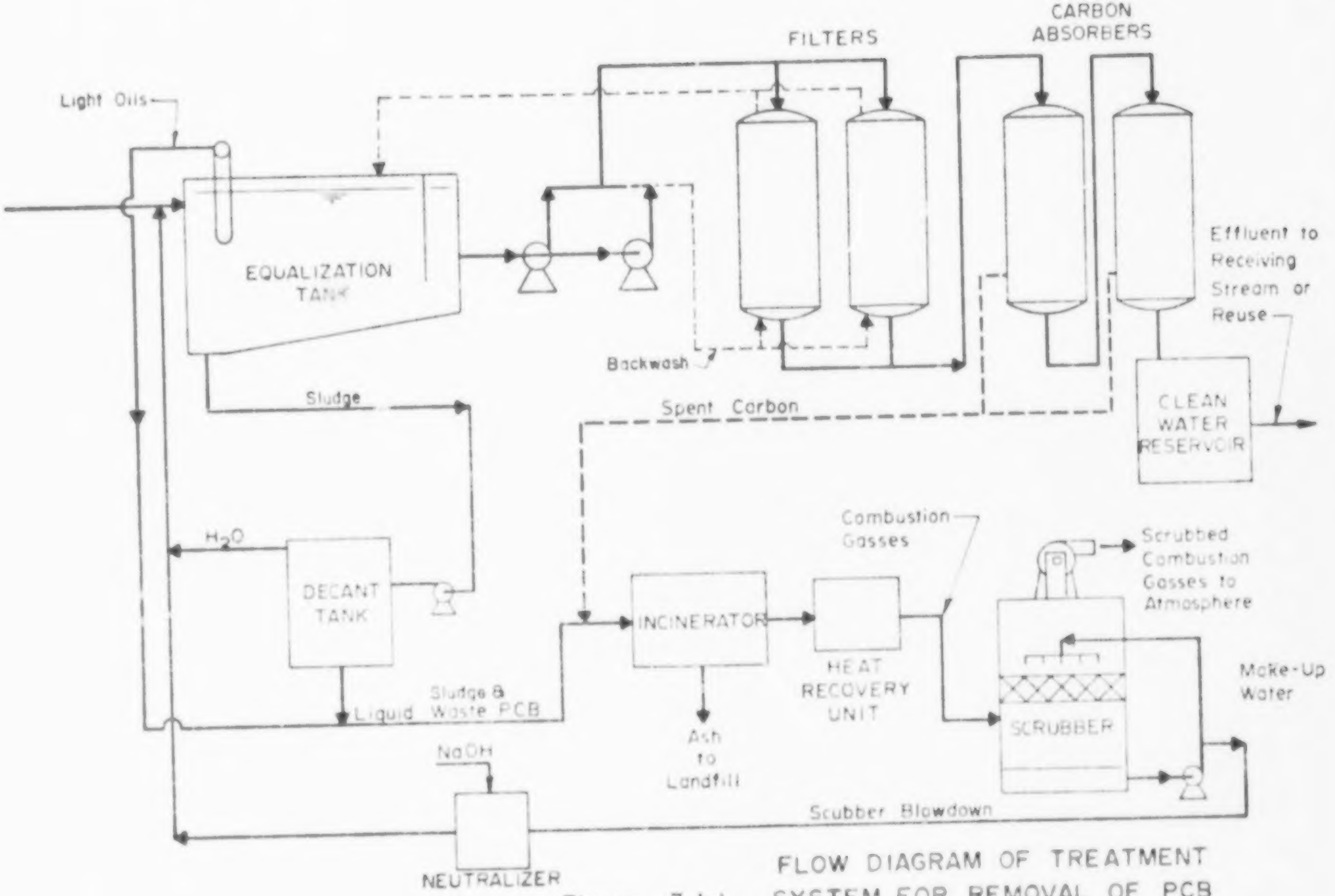

FILTERS
CARBON ABSORBERS
Light Oils
EQUALIZATION TANK
Backwash
Effluent to Receiving Stream or Reuse
Sludge
Spent Carbon
CLEAN WATER RESERVOIR
H2O
DECANT TANK
Combustion Gasses
Scrubbed Combustion Gasses to Atmosphere
INCINERATOR
Sludge & Liquid Waste PCB
HEAT RECOVERY UNIT
SCRUBBER
Make-Up Water
Ash to Landfill
NaOH
Scubber Blowdown
NEUTRALIZER

Figure 3.1-1 FLOW DIAGRAM OF TREATMENT SYSTEM FOR REMOVAL OF PCB FROM WASTE WATER

Ozonation using ultraviolet light radiation has been shown to be an alternative treatment method. Although, as a waste treatment method it has not found application, it has been used in chemical reaction technology.

The main difference between the operations of the two systems is the quality of the effluent and the need for regeneration for the carbon. The activated carbon adsorption process will adsorb all substances which are capable of entering the particles' pores. This means that any PCB present in the wastewater has the potential of being completely removed until breakthrough of the bed occurs. The ultraviolet light catalyzed reaction appears to approximate a first order reaction and the effluent concentration is therefore a function of the residence time in the reaction zone.

3.2 Pretreatment

3.2.1 Equalization and Separation Basin

The equalization basin's primary function is to equalize flow so the feed to the downstream treatment units is nearly constant. Since the flow variation could not be computed except on a case by case basis, an arbitrary sizing calculation was used. The volume was calculated using three times the design flow and a 24 hour residence time. This basis reflects consideration of discharge data for two of the manufacturing plants visited. The maximum liquid depth was assumed to be ten feet with an allowance of three feet of freeboard to prevent slop-over due to wave action.

Several methods can be used to ensure that collected wastewater does not enter the subsurface ground water. These are:

1. Utilize existing soil conditions where the soil strata is relatively impermeable
2. Line the basin with bentonite
3. Line the basin with an impermeable organic membrane
4. Construct the basin with reinforced concrete.

The wastewater entering the basin will probably contain suspended PCBs, oils and solvents. It is expected that PCBs will attack and deteriorate a synthetic organic liner. At this time the alternative that has the best chance of succeeding in containing the wastewater appears to be reinforced concrete construction. A sloped bottom at the head end of the basin will allow settleable solids and oils to accumulate for subsequent removal by pumping. It is anticipated that the settleable solids collected will be small compared with collected PCBs and this material will be pumped to a decant tank. Here water can be more easily separated and the heavy material can be drummed for later incineration.

A belt skimmer should be provided to remove floating oils. These can be accumulated in a drum; and when filled, it can be removed for incineration and replaced with an empty drum.

The basin influent would be pumped utilizing a lift station designed for the design flow plus runoff from a one hour, 25 year storm vary between two and four inches of rain per hour depending on geographical location. This figure may be obtained from the Rainfall Frequency Atlas of the United States, Technical Paper No. 40, U.S. Dept. of Commerce. The total flow, of course, will depend on the area drained. It is assumed that this area is not a function of production facility size and any attempt to size an influent pump station would introduce an unknown error. For this reason, the cost of this operation is not included in the cost estimates. It is believed that this cost will not affect overall capital costs significantly. The effluent pump station was designed on the design flow rate at 270 feet of water discharge head.

The decant tank can only be sized knowing the volume of oily material to be separated. The sizes were arbitrarily picked as 1000, 5000 and 10,000 gallon vessels. The flows through 80 gpm would utilize a 1000 gallon tank, for 160 through 640 gpm a 5000 gallon vessel and for 1700 gpm the 10,000 gallon tank would be utilized. The water layer would be recycled to the equalization basin while the underflow would be drummed for subsequent incineration.

3.2.1.1 Equalization Basin Capital and Operating Cost

The fact that reinforced concrete has been chosen to provide a barrier between the water environment and the basin makes this one module the single most expensive item in the total capital cost of a treatment system for removal of PCBs from wastewater. If rainwater runoff is inconsequential, then the size of the basin can be reduced significantly. If ventilation of the PCB handling areas is controlled and all such areas are enclosed, provided there is no prior ground contamination, rainwater runoff will be nonexistent in the sizing of an equalization basin. If this is the case, the capital cost commitment with this operation can be reduced by about a third. However, at present this is not the case.

The capital cost is shown in Figure 3.2.1-1 and the backup data for these costs is exhibited in Table 3.2.1-1.

3.2.1.2 Equalization Basin Costs

The capital cost of the equalization basin was calculated using $5.00 per cubic yard of earth removed and $285 per cubic yard of reinforced concrete for construction.

The annual operating and maintenance costs for the basin were calculated using 1.0% of the capital cost. The capital cost was amortized using an interest rate of 8% and a project life of ten years.

Pump operating and maintenance costs were figured at 2% of the total station capital cost.

3.2.2 Multimedia Filtration

Multimedia filtration using beds of sand and anthracite was chosen as a final suspended solids polish system. It would be advantageous to remove these solids to as low a concentration as possible to prevent them from passing through any subsequent treatment system designed for removal of soluble contaminants. Depending on the settleability of the solids in the equalization basin, chemical and/or polyelectrolyte addition to the filter feed may be desirable. It should be recognized that chemical addition such as alum, lime or iron salts

FIGURE 5.2.1-1

FLOW EQUALIZATION BASIN INSTALLED CAPITAL COST

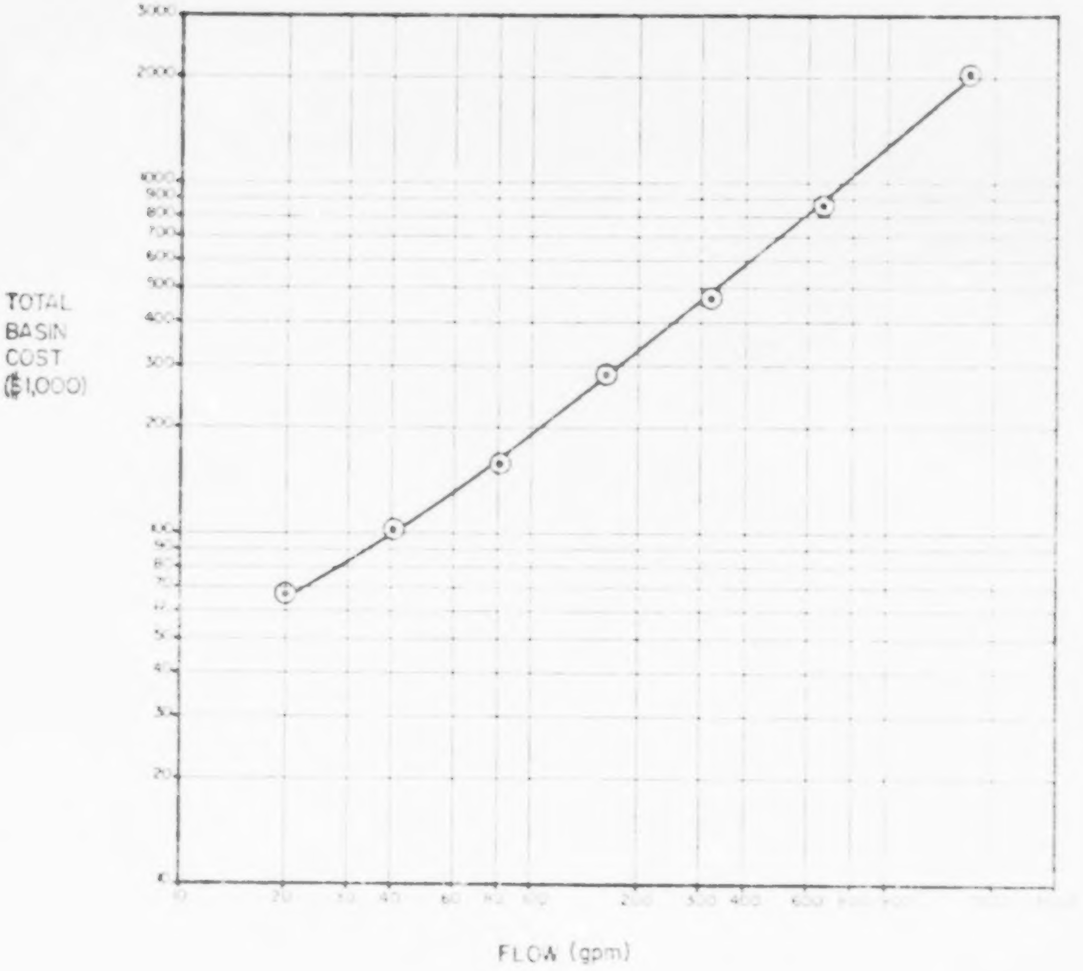


TABLE 3.2.1-1

FLOW EQUALIZATION BASIN SIZING AND COSTS

BASIS:
1. 24 hour retention
2. 3 times normal flow
3. 18" concrete
4. 12 ft. depth
5. 10 ft. water depth
6. L/W = 2.0

FLOW (GPM)	20	40	80	160	320	640	1700
LIQUID VOLUME (1000 gal)	86	176	345	690	1380	2760	7340
WIDTH (ft)	24	34	48	68	96	136	222
LENGTH (ft)	48	68	96	136	192	272	444
EXCAVATION COST ($1000)	2.6	5.1	10.2	20.5	41	82	218
CONCRETE COST ($1000)	45.6	75.6	128	224	402	742	1820
TOTAL BASIN COST ($1000)	48	81	138	245	443	824	2038
PUMPS AND SUMP ($1000)	20	20	21	22	27	32	42
TOTAL BASIN & PUMP COST ($1000)	68	101	159	267	470	856	2080

will increase solids handling problems and all solids must be sent to incineration. It is anticipated that the source of solids will be soil washed into the treatment system by rainfall and carried into production areas by workers. Care should be used so that other processes which might supply organic solids and are free of PCB contamination are not included in the PCB pretreatment system.

There is a possibility that chloride concentration in the filter feed would be such that mild steel construction would not be acceptable. Possible absorption of organic contaminants in an organic liner used to preclude corrosion is expected and therefore all stainless steel (Type 304) construction is suggested.

Although pilot testing of a filter system is suggested to obtain optimum flow rates and bed depths, this is impossible for the systems described in this report. Superficial velocities of 0.5 to 6 gpm/ft.^{2} have been used with success. For the system design described in this section, superficial velocities of 1.5 to 3 gpm/ft.^{2} were used.

It was assumed that a 12 foot diameter vessel would be the largest size used due to the difference in shop and field fabrication costs. Only in the case of the 1700 gpm flow would this pose a problem in making the decision to provide shop or field fabricated vessels. Since the choice of stainless steel construction was made, it was found that for this case, shop fabrication would be less expensive even when the cost of added valving and piping was considered.

Filters would be arranged for parallel flow, and in all cases through 640 gpm, the number of filters would be two. Each filter would be capable of treating the entire flow when the other was off line for backwash. This time period would be a maximum of 30 minutes per day.

Backwash flow would be at 20 gpm/ft.^{2} and increased from 10 to 20 gpm/ft.^{2} in 5 gpm/ft.^{2} increments lasting about two to three minutes. When backwash has been completed, a rinse cycle would be used for about ten minutes to settle the bed using clean water from the clean water reservoir.

The flow rate through each filter would be half that through each carbon adsorber. The filter requirement would be the same as the adsorber requirement. For example, if two, seven foot diameter carbon adsorbers are required in series, then two, seven foot filters would be required arranged for parallel flow.

[illegible] Filtration Costs

The capital cost of the filtration system was assumed to be equal to that of the carbon adsorber system since like vessels would be used. The operating and maintenance costs were calculated from work performed by Burns and Roe.[illegible] The operating and maintenance cost curve which was for March 1969 may be represented by the equation

O&M Cost = [illegible]

where:

Cost = ¢/1000 gal

Q = [illegible]

[illegible] were increased by [illegible] changing the equation to:

Cost = [illegible]

The combined costs of equalization, [illegible] and filtration [illegible] total capital cost. The total installed pretreatment system costs and annual operating costs are enumerated in Tables [illegible] and 2, respectively. Graphical representations of these costs can be seen in Figures [illegible] and [illegible] [illegible]

[illegible] Activated Carbon Treatment System for Removal of [illegible] Wastewater

Activated carbon has the property of adsorbing substances, [illegible] in [illegible]. This adsorption may be caused by three mechanisms: (1) Van der Waals forces, (2) electrostatic factors, (3) hydrogen bonding. Van der Waals forces [illegible] between surface molecules that produce a liquid such as carbon tetrachloride [illegible] under standard conditions, are the predominant mechanism of adsorption on activated carbon.

TABLE 3.2.2-1

TOTAL INSTALLED PRETREATMENT SYSTEM COST
($1000)

FLOW (gpm)	20	40	80	160	320	640	1700
EQUALIZATION BASIN	68	101	159	267	470	856	2080
FILTER SYSTEM	32	40	62	78	120	200	600
DECANT TANK	3	3	3	7	7	7	12
TOTAL MODULAR COST	103	144	224	352	597	1063	2692
PIPING AND INSTRUMENTATION (25%)	26	36	56	88	149	267	673
TOTAL INSTALLED EQUIPMENT COST	129	180	280	440	764	1330	3365
ENGINEERING (10%)	13	18	28	44	75	133	334
TOTAL PRETREATMENT PLANT COST	142	198	308	484	821	1463	3699

TABLE 3.2.2-2

ANNUAL OPERATING COST FOR PRETREATMENT FOR REMOVAL OF PCB FROM WASTEWATER
($1000)

FLOW (GPM)	20	40	80	160	320	640	1700
AMORTIZATION (8%-10 yr)	21	30	46	72	122	218	551
OPERATION & MAINTENANCE	4	6	8	13	20	32	63
POWER (2¢/KWH)	-	1	2	4	8	17	45
ANNUAL PRETREATMENT COST	25	37	56	89	150	267	659
COST/1000 GAL ($)	2.38	1.76	1.33	1.06	0.89	0.79	0.74

FIGURE 3.2.2-1

PRETREATMENT SYSTEM CAPITAL COST

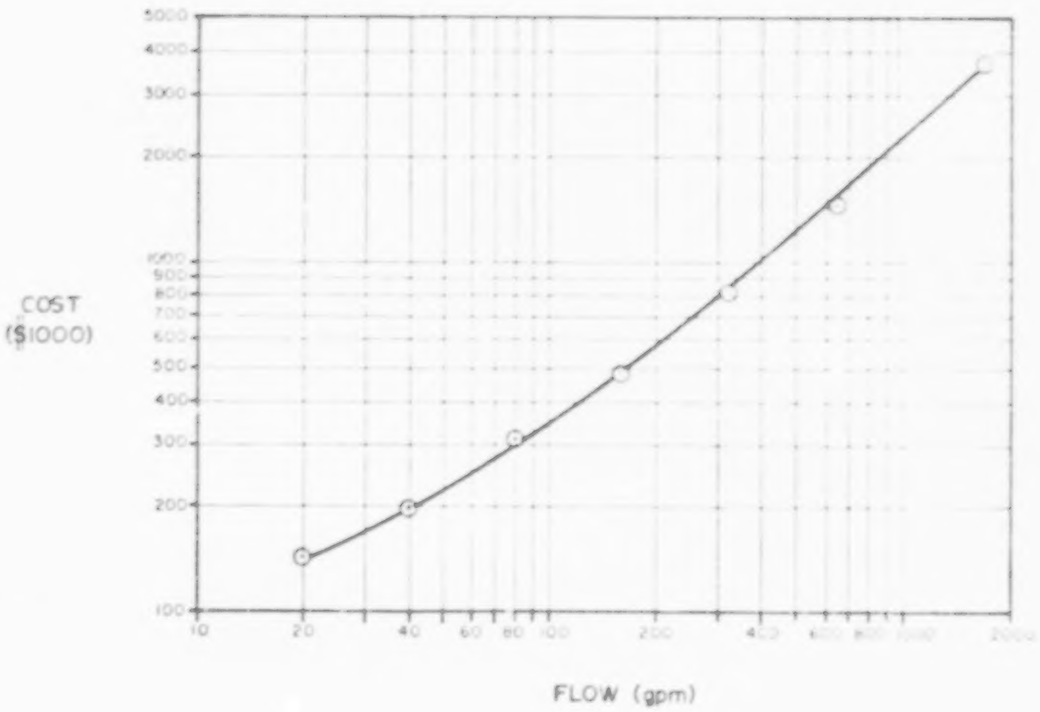
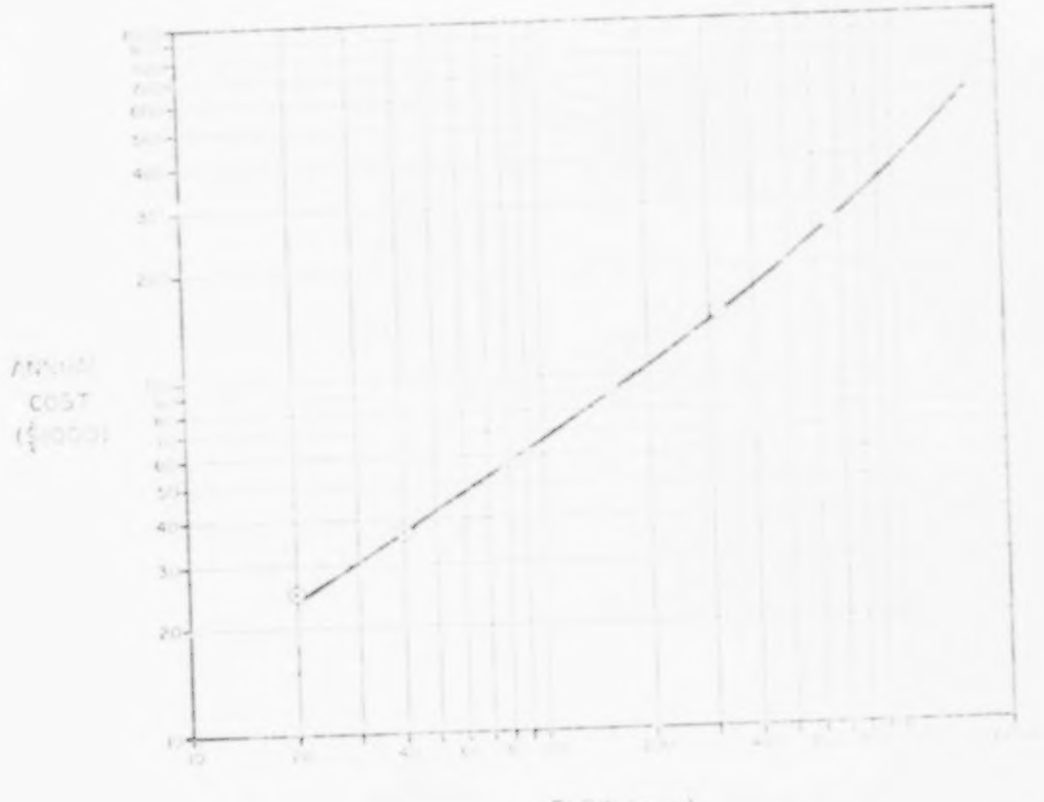


FIGURE [illegible]

ANNUAL COST FOR PRETREATMENT



The pore size distribution is a crucial factor in adsorption. For treatment of wastewater, a large range is required due to the complexity of the wastewater where everything from methanol to long chain hydrocarbons are possible. If the pore size is too small, larger molecules will be screened since they will not be able to move into the carbon particle. A typical value of the surface area of carbon is 1000 m^2/g and this indicates that most of this area is in the inside of the carbon granule. Because of this large internal surface area, organic molecules may be removed from water solution by the adsorption process. Desirable pore diameters range from 20 to 80 Angstroms. Since most wastewaters do not contain an individual organic component dissolved in water, a number of molecules must compete for the available carbon surface area. As can be seen in Table [illegible], a chemical oxygen demand (COD) of 30 mg/l is anticipated, with an effluent concentration from the carbon system expected to be 10 mg/l.

The PCB concentration is expected to be 50 parts per billion and this is anticipated to be removed to a level of 1 ppb or less by the activated carbon beds. At present, there are no known tests that have been performed that provide a reliable figure on the exhaustion of activated carbon in column adsorption using PCB contaminated wastewater. Data using PCBs was developed by [illegible] Corporation and Calgon Corporation (a subsidiary of Merck & Co., Inc.) by isotherm testing. PCBs were the major organic contaminant in the water during these tests. Methanol was present as a solvent in ppm quantities. These tests can be said to be static in nature, whereas a column test would be dynamic, and would approximate the conditions expected in a full scale system. However, since this is the only usable data available, it will be used in this study. The carbon's capacity for COD is anticipated to be 0.25 pounds of COD per pound of carbon, whereas the PCB capacity is anticipated to be .006 pounds of PCB per pound of carbon. Based on the anticipated concentrations from Table [illegible].3-1, the usage rate of carbon based on COD alone would be 0.667 pounds per 1000 gallons, while that for PCB would be 0.0695 pounds per 1000 gallons. From this it can be seen that COD and not PCBs would be the controlling factor on the operational cost of any activated carbon system since it is believed that the activated carbon would become saturated with COD and at that point PCBs would not be preferentially adsorbed. This is a

TABLE 3.3-1

CARBON SYSTEM FEED CHARACTERISTICS

	Feed	Effluent
PCB (PPB)	50	<1
HEXANE SOLUBLE SUBSTANCES (mg/l)	5	<1
COD (mg/l)	30	10
SUSPENDED SOLIDS (mg/l)	10	<1

gross assumption and may be disproved at a later time when lengthy column studies have been completed. It should be noted that since COD is assumed to be the limiting factor in this case, it would be to the user's advantage to limit the quantity of organics that enter any system designed to protect the environment from PCBs.

3.3.1 Activated Carbon System Design

The parameters used for this study to design an activated carbon adsorption system may be seen in Table 3.3.1-1. These parameters were arbitrarily chosen and were not developed by testing using PCB waste. They are, however, based on past experience from a number of studies in actual treatment facilities. The material of construction was chosen as Type 304-L Stainless Steel, since the activated carbon will cause electrolytic corrosion of any mild steel vessel in which it is used. Mild steel vessels can be internally, organically coated; however, it is anticipated that as the activated carbon becomes saturated with PCBs, that this may tend to dissolve in the organic coating, loosen the bonding between the coating and the steel and cause removal of this coating from the vessel wall. At this point severe corrosion may begin with ultimate failure of the vessel. It is also foreseen that periodic internal cleaning of the vessels will be necessary and this organic coating would be a hindrance to the use of a number of solvents that may best remove PCBs from the surface.

Since PCBs are not considered acidic or basic in nature, pH should not have a strong affect on the adsorption process, and therefore does not necessarily have to be stringently controlled. However, for protection of external piping and valving, it is suggested that the pH should be in the neighborhood of 6.5 to 9. At pH's above 9, there is a possibility of producing a non-breakable emulsion of oils which may tend to pass through all systems untreated and of damaging the equalization basin.

Due to the expected low usage of activated carbon in this system, only static bed contacting systems will be investigated. These will include two adsorbers arranged in series operation. They will be operated until PCBs are detected in the effluent of the lead column. At this point the lead column would

TABLE 3.3.1-1

CARBON SYSTEM DESIGN CRITERIA

SUPERFICIAL VELOCITY (gpm/ft^2)	3-6
CARBON VOID FRACTION	0.4
CARBON DENSITY-BACKWASHED AND DRAINED (#/ft^3)	25-28
SUPERFICIAL RESIDENCE TIME (min)	15
ACTUAL RESIDENCE TIME IN BED (min)	6
DESIGN MAX PRESSURE (Psig)	50
ACTUAL MAX PRESSURE (Psig)	30
PCB/CARBON CAPACITY (lb/lb)	.006
TOC/CARBON CAPACITY (lb/lb)	.25

be removed from the line, the carbon removed and virgin or regenerated carbon installed. At this point the polish column would be valved into the lead position and the previous lead column would be in the polish position. When the carbon becomes spent, it can be discarded or regenerated thermally.

The virgin carbon replacement should be added to an adsorber water level approximately one-third the depth of the vessel to prevent massive air pockets from forming. This carbon should be allowed to wet for approximately 24 hours either before addition or after addition to the adsorber. When the carbon charge has been completed the charge opening should be closed and the adsorber placed on backwash. The recommended backwash procedure would be 5 gpm/ft² for five minutes, 10 gpm/ft² for five minutes and 12 to 15 gpm/ft² for ten minutes. This will allow a controlled expansion of the bed and prevent massive disruptions at the surface as would be experienced if the full backwash of 12 to 15 gpm/ft² were used initially. A number of possible flow situations have been investigated and the data relating to these may be seen in Tables 3.3.1-2 and 3.3.1-3 and Figure 3.3.1-1. It has been found that field erection of stainless steel vessels is considerably higher than shop fabrication. For this reason no adsorber larger than 12 feet in diameter has been investigated.

Although no suspended solids buildup in the bed is foreseen, a surface wash is recommended for any possible upset of the upstream facilities. This will be a rotating pipe arrangement that will expand the top 6 to 12 inches of the bed without full backwash. The carbon will act as a filter and remove suspended solids from the wastewater to a point where breakthrough occurs. At this point it is anticipated that the solids, which possibly contain adsorbed PCBs, will cause a premature breakthrough of the carbon bed. It is therefore recommended that backwashing be attempted at least on a weekly basis. If COD concentration is high and sanitary facilities are involved in the contribution of this COD, then septic conditions could occur. If this happens, backwash should be performed daily.

A number of underdrain systems are commercially available. However, it is strongly suggested that any underdrain containing plastic materials

TABLE 3.3.1-2

CARBON ADSORPTION SYSTEM
SIZING AND COSTS

FLOW (gpm)	20	40	80	160	320	640	1700
SUPERFICIAL VELOCITY (gpm/ft)	3	3	3	4	5	6	6
VESSEL DIAMETER (ft)	3	4	6	7	9	12	12
RESIDENCE TIME (min/adsorber)	6.1	6.0	6.3	6.0	6.1	6.3	6.3
BED DEPTH (ft/adsorber)	5.7	6.4	6.0	8.3	10.2	12.0	12.0
VESSEL HEIGHT (ft)	9	10	10	13	16	19	19
BED VOLUME (ft /adsorber)	40	81	170	320	650	1360	1360
CARBON WEIGHT (lb/adsorber)	1090	2170	4600	8650	17550	36700	36700
CARBON COST ($/adsorber)	55	1085	2300	4325	8770	18350	18350
UNIT ADSORBER COST ($1000)	13	16	25	31	48	80	80
UNIT INSTALLATION ($1000)	3	4	6	8	12	20	20
TOTAL UNIT COST ($1000)	16	21	33	43	69	118	118
NUMBER OF ADSORBERS	2	2	2	2	2	2	6
TOTAL ADSORPTION SYSTEM COST ($1000)	32	42	66	86	138	236	708

TABLE 3.3.1-3

ACTIVATED CARBON ADSORPTION SYSTEM ANNUAL OPERATING COSTS

(\$1000)

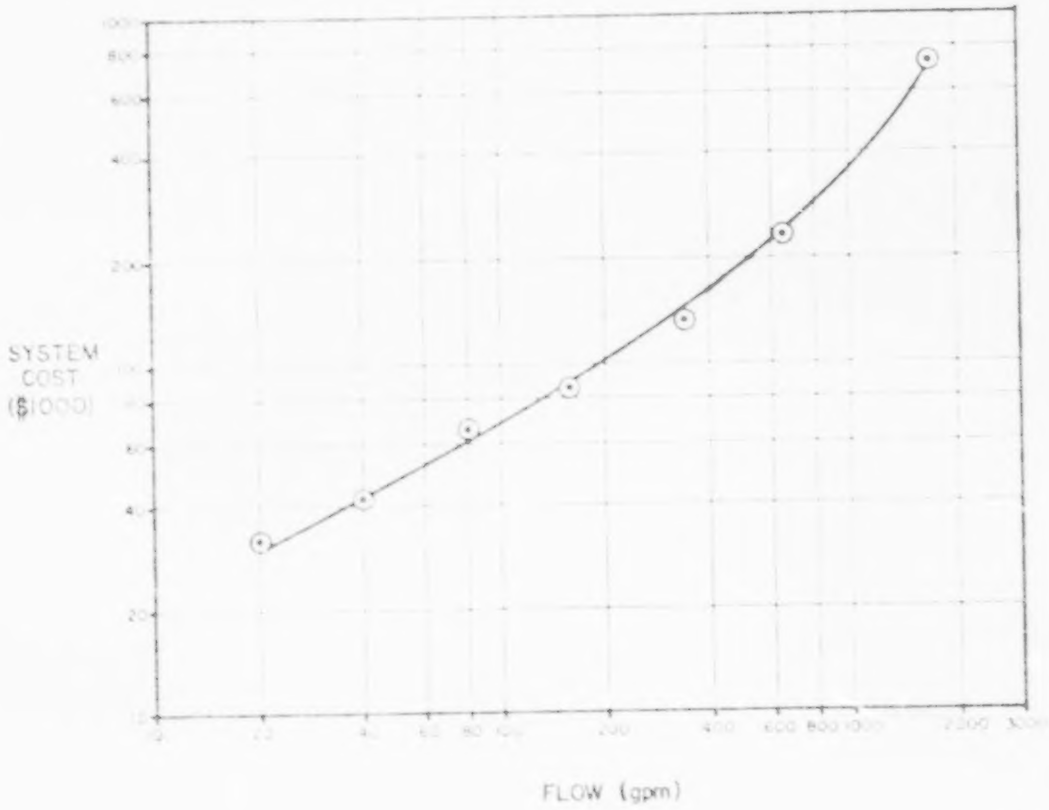
FLOW (gpm)	20	40	80	160	320	640	1700
YEARLY CARBON COST	3.5[1]	7.0[1]	14.0[1]	28.0[1]	47[2]	70[2]	137[2]
CARBON SYSTEM AMORTIZATION (8% - 10 yrs)	4.8	6.3	9.8	12.8	21	35	104
LABOR AND MAINTENANCE	10.3	10.9	12.5	14.8	17	27	56
PUMPING-COST (2¢ KWH)	0.2	0.2	0.7	1.1	3	5	14
ANNUAL OPERATING COST	18.8	24.4	37.0	56.7	88	137	311
COST/1000 GAL ($)	1.79	1.16	0.88	0.67	0.52	0.41	0.37

[1] Spent carbon replaced by virgin carbon [illegible]

[2] On-site regeneration.

FIGURE [illegible]

ACTIVATED CARBON SYSTEM INSTALLED COST



should not be used for this particular application, due to the possible impregnation of the plastic with PCBs. Stainless steel should be used as the underdrain system and this can either be installed by bolting or welding to the vessel. This underdrain performs three important tasks.

1. Support of the activated carbon bed.
2. Allow passage of the processed wastewater from the bed to a penum located at the bottom of the absorber.
3. Uniform distribution of the backwash water.

Three basic types of underdrains are presently in use. They include:

1. Well screen
2. Neva-Clog (a product of Multi-Metal Wire Cloth, Inc.)
3. Individual nozzles which provide even distribution of the backwash water; installed at predetermined spots in a support plate.

For the purpose of this study, removal of activated carbon will not be performed through the support plates or any underdrains. The activated carbon will be removed from an access port at the side of the vessel, either hydraulically or physically. Hydraulic removal is recommended and this can be done with an eductor while backwashing at approximately 2 to 3 gpm/ft^2. Slurry concentrations of 1 to 4 lbs/gal have been experienced but 1 lb/gal is average. Suggested pipeline velocity is 3 to 6 feet/second.

Typical granular activated carbon specifications may be seen in Table 3.3.1-4. Molasses decolorizing index and iodine number have been included to provide the user with a relationship that would give information as to the macropore volume and micropore volume of the activated carbon. The iodine number may be related to the total pore volume of the activated carbon, including micro and macropores whereas the molasses decolorizing index provides information as to the larger pores (greater than 30 Angstroms in diameter). Activated carbons with large molasses decolorizing indices tend to provide a higher rate of absorption

TABLE 3.3.1-4

TYPICAL ACTIVATED CARBON SPECIFICATIONS

MOLASSES DECOLORIZING INDEX (min)	6.3
IODINE NUMBER (min)	900
ABRASION NUMBER (min)	70
MOISTURE WHEN PACKED (70, max)	2
ASH (%, max)	8.0
PARTICLE SIZE (U.S. Sieve Series)	8 x 30
OVERSIZE (%, max)	8
UNDERSIZE (%, max)	5

over those with lower numbers. However, the total working capacity of the activated carbons that have the higher numbers might tend to be less than those with the lower numbers if the iodine numbers are essentially the same. For virgin carbons, the iodine number tends to be the major source of absorptive information available to the knowledgeable consumer and the use of the molasses decolorizing index may be dropped without any appreciable decrease in quality of the activated carbon.

Granular activated carbon has been chosen for this application since the requirement is for very low to zero discharge of PCBs. Powdered activated carbon is also available; however, it is questioned whether it may be used successfully for this application.

3.3.1.1 Regeneration of Spent Carbon

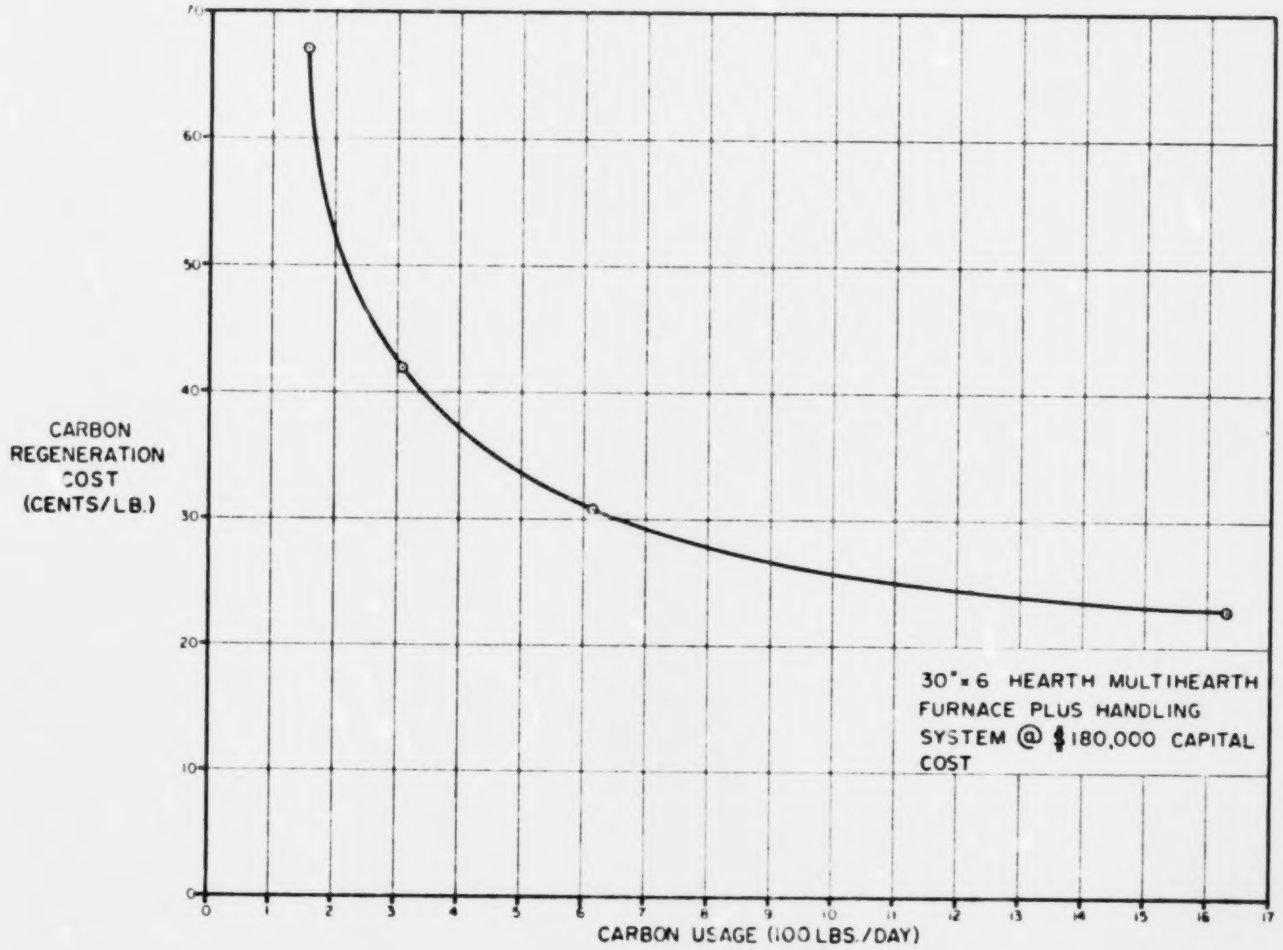
It has been mentioned that due to the low usage rate of the activated carbon, it should be used on a throw away basis. There is a possibility of thermal regeneration for this activated carbon. Other possible regeneration techniques are solvent extraction, chemical regeneration and steaming. Due to the high efficiency required of the carbon beds, it is strongly suggested that solvent extraction not be utilized. Since the nature of the PCB molecule is not acidic or basic, chemical regeneration will not apply here. Due to the high boiling point, and therefore extremely low vapor pressure of PCBs, steaming at any available steam pressure is not recommended for removal of these PCBs. This leaves only thermal regeneration.

Carbon regeneration costs were developed using a 30 inch, six hearth furnace at an installed capital cost of $180,000, including carbon handling system. These costs are shown in Figure 3.3.1.1-1.

A number of physical and chemical operations are involved in thermal regeneration. Carbon used in liquid service is dewatered by mechanical means to 30 to 40% moisture and fed to the thermal regeneration furnace. The first section dewaters the carbon completely by vaporization at temperatures up to 300°F. As the carbon passes through the furnace, the temperature increases

FIGURE 3.3.1.1-1

CARBON REGENERATION COST VS. USAGE



due to countercurrent flow of carbon and gases. The next step is removal of volatile organic compounds which is performed at temperatures of 300° to 600°F. Those organic compounds which are not removed by volatilization remain in the carbon pores and are thermally decomposed, leaving an amorphous carbon residue at temperatures of 600° to 1200°F. This can be called a charring step. The last and most important step of the thermal regeneration process is removal of the char from the pores and can be called reactivation.

Since this char cannot be physically removed from the carbon, it must be chemically removed This can be done by selective oxidation. Oxygen reacts with carbon to produce gaseous carbon monoxide and carbon dioxide which can be removed with the combustion gases. This reaction occurs at temperatures of 600°F and is exothermic. It is difficult to control since the oxygen attacks the carbon granule as well as the char in the pore. In fact, the action is so fast that at temperatures above 1000°F the oxygen reacts with the first carbon with which it comes in contact. This means that it will preferentially oxidize the carbon of the granule and deteriorate it.

Another method of removing the charred deposit is to use steam. Steam reacts with the carbon to produce gaseous carbon monoxide and hydrogen which can be removed with products of combustion in a direct fired system. This reaction is endothermic and tends to be quite controllable. Between 1200 and 1500°F, the rate is quite low and not very effective for removal of char. At temperatures above 1500°F it is effective and between 1500° and 1700°F the steam reacts preferentially with the amorphous char deposit in the pores. The reaction with the crystalline, graphitic structure of the original granule is much slower. As the temperature increases beyond 1700°F, the reaction becomes less selective. Thus, the effective temperature range for the char removal step with steam is 1550° to 1700°F. A steam to carbon ratio can be as high as 1:1 but normally it is 0.5:1.

At temperatures above 1700°F some of the fine micropores are sacrificed for large micropores. In most cases, the small micropores (less than 30 Angstroms diameter) are the pores which contribute to the absorption of low molecular weight organic compounds. It is anticipated that PCBs will fall in this range. When these are widened, the compounds are not held as tightly, and therefore the capacity of the carbon for the simple organic compounds decreases. The optimum regeneration keeps the micropore volume constant. In most cases it is advisable to sacrifice some of the micropore volume (tip of the pore) in order that the granule is not subjected to over regeneration. Usually this amounts to about 5% of the virgin micropore volume.

It has been shown that destruction of PCBs at temperatures above 1600°F is effective in about 99.997% efficiency.(3) Since most commercial PCB users utilize the lower boiling (about 400°F) PCBs, then most of these compounds would be vaporized from the activated carbon before it reached the 1600° to 1700°F portion of the reactivation furnace. These will then be expelled with the combustion gases from the furnace before they could be decomposed. For this reason an afterburner would be required that would have a minimum temperature of 1600° and maximum temperature of 2000°F. Retention times in the afterburner have been shown to be between 0.10 and 0.11 seconds. Commercial installations utilizing retention times of 2 to 3 seconds for decomposition of PCBs are in use. The combustion gases from a reactivation furnace should pass through such an afterburner system. This should be scrubbed to remove any particulate contaminating PCBs and HCl formed in the decomposition steps.

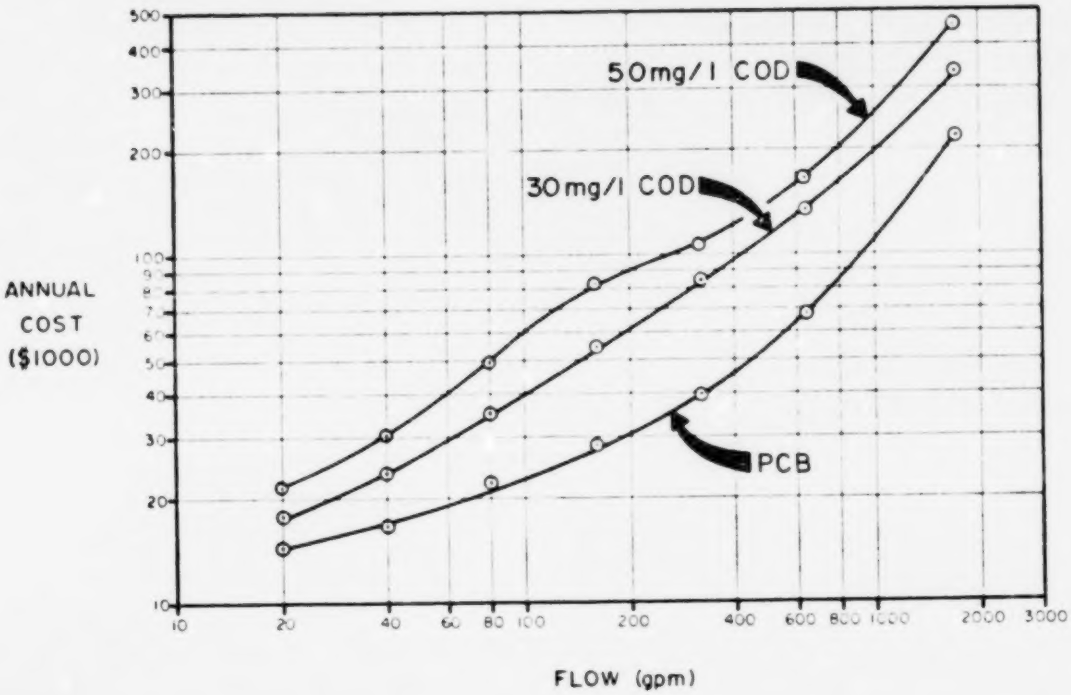
Any thermal regeneration process should be strictly monitored for residual PCBs in the gaseous effluent and also any remaining in the granular activated carbon that has been regenerated. It is strongly suggested that any regeneration facilities designed for reactivating PCB carbon should isolate that carbon from any other carbon to be regenerated. In other words, the reactivation facility should be dedicated to PCB use only. This will ensure that carbon that has not been contaminated with PCBs previously will not be cross contaminated with that which has been used for PCB cleanup.

3.3.1.2 Economic Analysis of Carbon Treatment of PCB Contaminated Wastewater

Figure 3.3.1.2-1 graphically depicts the different operating costs between a waste stream containing only PCBs and one with other organic contaminants that provide COD adsorption differentials of 20 and 40 mg/l

FIGURE 3.3.1.2-1

ACTIVATED CARBON
WASTEWATER TREATMENT SYSTEM
TOTAL ANNUAL COST
BASED ON DIFFERENT
CONTAMINANT PARAMETERS



(feed concentration of 30 and 50 mg/l). The only cost differential contemplated is the difference between the carbon usage for the three streams. This cost differential indicates that it would be to the treaters' benefit to isolate and treat only those streams contaminated with PCBs. It could also be to their benefit to remove any stream which is free of PCBs, but containing carbonaceous COD from the treatment scheme. It is evident from Figure 3.3.1.1-1 that carbon usage rates less than 200 lbs. per day do not justify on-site regeneration when a virgin carbon cost of $0.50 per pound is used. Using the PCB isotherm data, it was found that no flow in the range studied would justify on-site regeneration. When using the assumed COD adsorption rate of 20 and 40 mg/l, it was found that regeneration on-site is economically feasible at flows above 210 gpm.

Toll regeneration could be utilized for systems using less than 200 lbs/day of carbon if the regeneration facility is equipped with sufficient safeguards to prevent contamination of other carbon by PCBs and ensure that air and water pollution does not occur. If this is possible, the operational costs for flows less than 210 gpm can be reduced accordingly since these were calculated using virgin carbon replacement of the spent carbon. This holds for all figures used to develop the PCB curve in Figure 3.3.1.2-1, also.

At flows above 640 gpm, parallel adsorber operation was required because of on-site fabrication cost of stainless steel vessels. Shop fabrication is less expensive than on-site fabrication of stainless steel pressure vessels. Twelve (12) feet is the maximum transportable diameter.

For a total treatment cost, the cost of equalization, filtration and incineration must be added to the capital cost for the adsorption system and $180,000 for on-site regeneration capital cost for flows above 210 gpm.

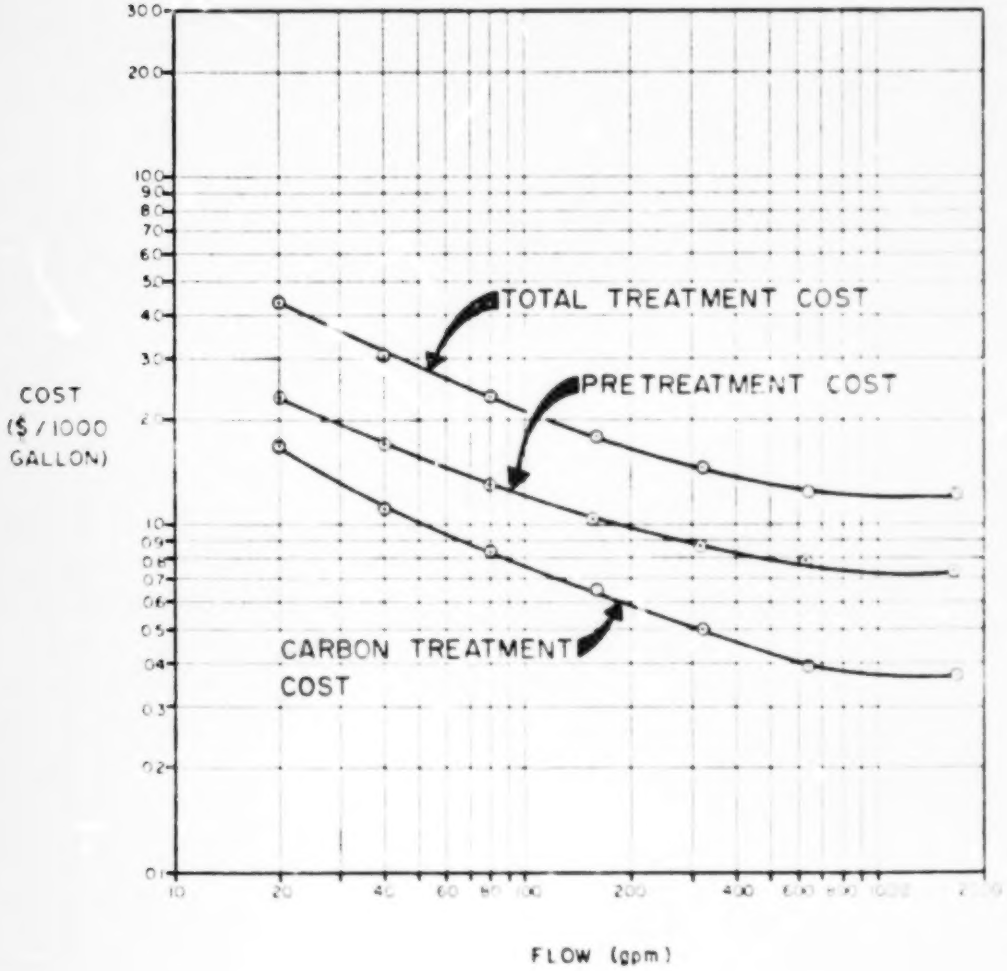
Figure 3.3.1.2-2 includes all amortized capital costs associated with the activated carbon system except disposal of spent activated carbon used in the incremental flow cases between 20 and 160 gpm.

3.3.2 UV-Ozonation - Potential Alternative

3.3.2.1 Description of System Components and Rationale for Cost Evaluation

FIGURE 3.3.1.2-2

COST PER 1000 GALLON FOR
PCB REMOVAL FROM WASTEWATER
WITH CARBON



The technology employed in a proposed PCB treatment system utilizing UV catalyzed ozonation has been described previously. Some description was also provided on scaling up Westgate Corporation's batch reactors for a continuous treatment system. Further discussion with Jack Zeff of Westgate and Dr. Robert Legen of Houston Research led to the conclusion that scaling up batch reactors for purposes of developing a PCB treatment system cost evaluation was not the best approach. Unfortunately, however, with the process still in its infancy (not much beyond laboratory development) no straight forward guidelines exist to generate cost data.

With this in mind, the approach taken in developing approximate cost data was to:

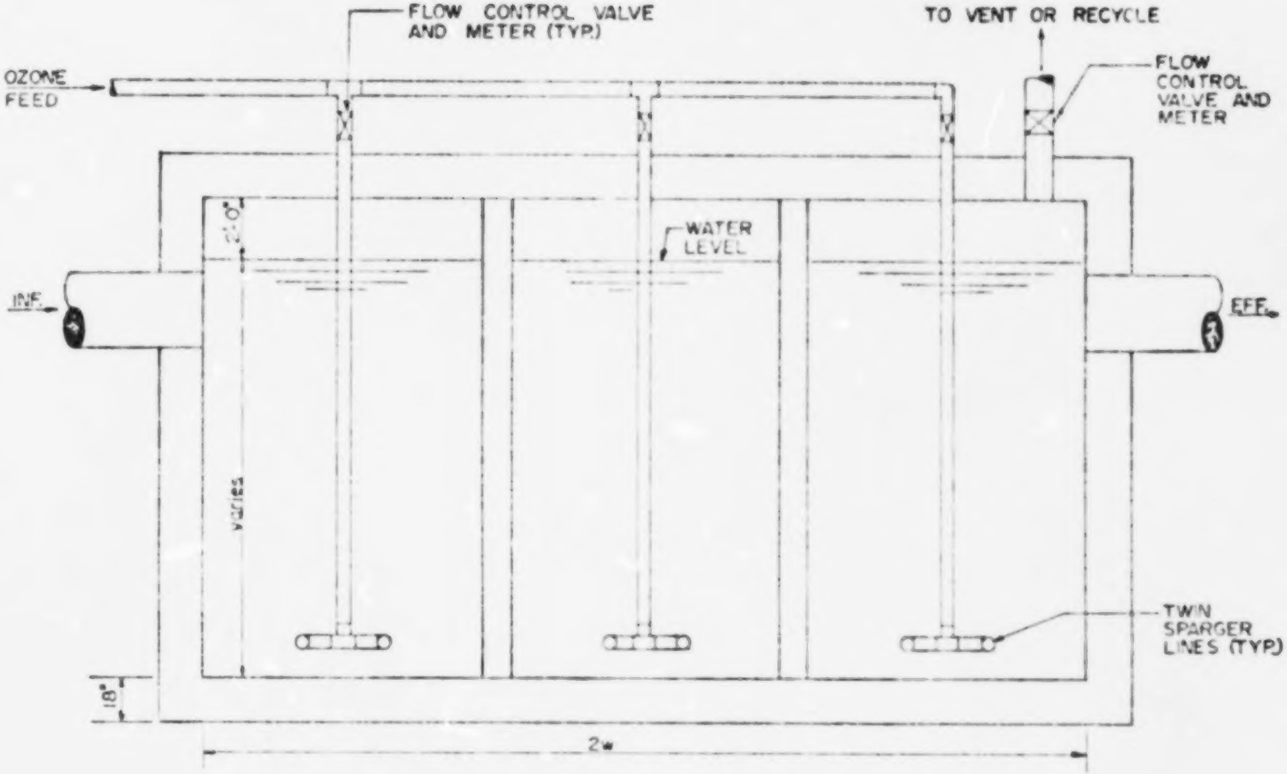
1) Design a reactor similar to a chlorine contact chamber;

2) Size this reactor based on estimated required residence times extrapolated from Houston Research Corporation's batch studies with PCBs;

3) Estimate the required O_3 production rate based upon recommendations by Houston Research for wastes containing only PCB plus the additional ozone demand exerted by the non-PCB COD in the waste;

4) Estimate the required number of UV lamps for a given reactor volume based on recommendations by Westgate for continuous systems.

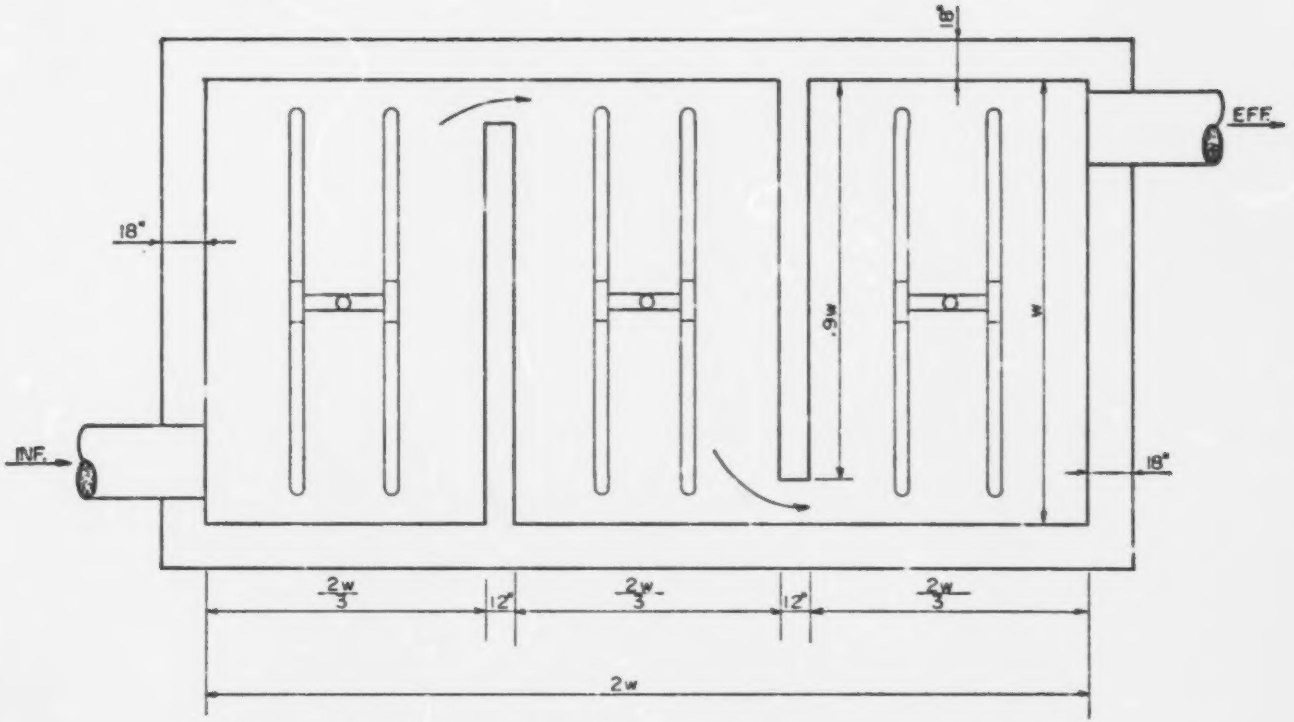
The reactor shown in Figure 3.3.2.1-1 is a three stage covered concrete tank. The length to width ratio was chosen as 2 to 1 to minimize short circuiting. The depth was chosen as 12 to 14 feet to maximize O_3 transfer efficiency. Spargers, located near the tank bottom, provide the required mixing as well as O_3 dissolution.


FLOW CONTROL VALVE AND METER (TYP.)
TO VENT OR RECYCLE
OZONE FEED
FLOW CONTROL VALVE AND METER
2'0"
WATER LEVEL
INF.
EFF.
varies
TWIN SPARGER LINES (TYP.)
18"
2w

Notes: UV Lamps Omitted For Clarity
W - Denotes Width

Figure 5.3.2.1-1

PROPOSED REACTOR CONFIGURATION - ELEVATION


18"
18"
18"
INF.
EFF.
.9w
w
2w/3
12"
2w/3
12"
2w/3
2w

Notes: UV Lamps Omitted For Clarity
W - Denotes Width

Figure 3.3.2.1-1 (Con't)

PROPOSED REACTOR CONFIGURATION - PLAN VIEW

Low pressure, non-phosphur coated fluorescent tubes (not shown in the sketch) would be stacked vertically throughout the tank to provide the required UV light. For a full scale system, Westgate suggested use of six 43-watt tubes for a reactor volume of 54 cubic feet. For conservation in the cost analysis, the number of lamps was determined based on use of one lamp per five cubic feet of reactor volume.

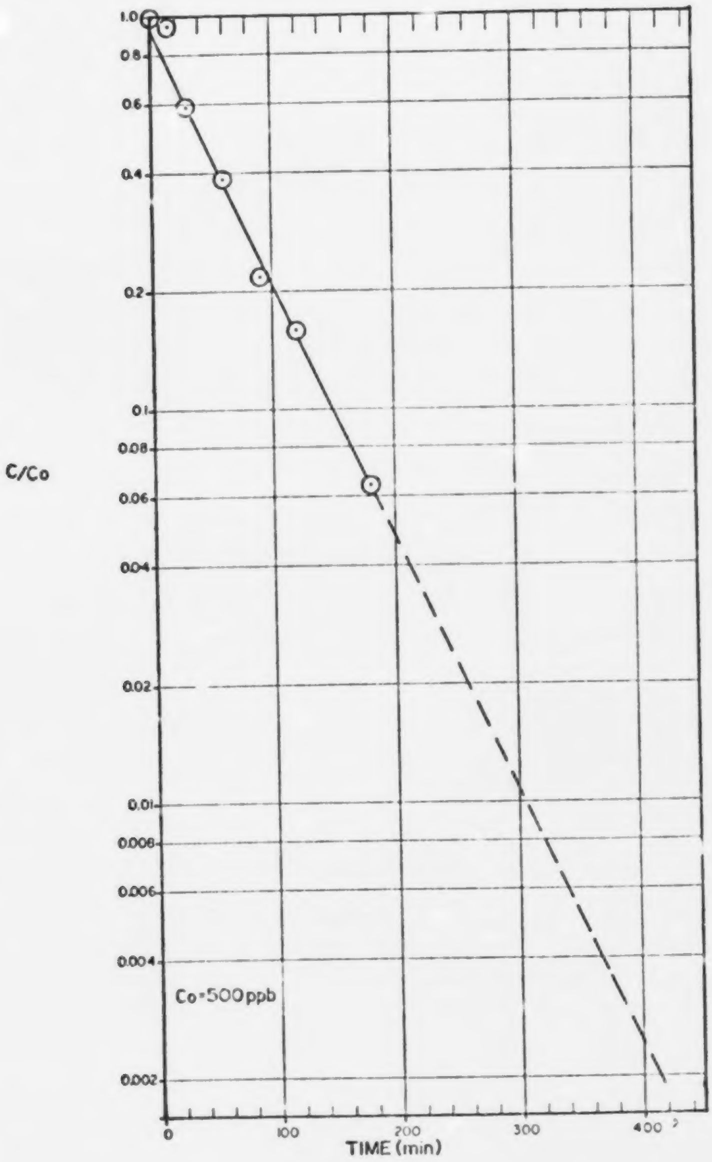
The reactor residence time was determined from a logarithmic plot of Houston Research batch study data. See Figure 3.3.2.1-2. The data show that the reaction rate approximates first order kinetics. This implies that the rate of PCB oxidation by this process is proportional to the PCB concentration and that very long residence times are required for final PCB concentrations on the order of 1 to 10 ppb. Extrapolating the logarithmic plot is necessary to determine the residence time necessary to get to these very low final concentrations. Houston Research batch studies did not go to PCB levels below about 30 ppb. It must be cautioned that extrapolating the plot might be producing very erroneous data. In other words, residence times far in excess of those calculated might be necessary to actually achieve the desired final PCB concentration. On the other hand, both Houston Research and Westgate claim that the process could be optimized such that shorter residence times would be required. Jack Zeff, though, stated that an optimization study of at least 4 to 6 months duration would be necessary before meaningful design residence times could be generated. For purposes of this cost analysis, the residence times generated from the extropolated data will be used. Four cases were looked at:

1) Filtration not included in pretreatment.
   Influent 200 ppb. Effluent PCB concentration 10 ppb. Residence Time --- 210 min.

2) Filtration not included in pretreatment.
   Influent PCB concentration 200 ppb.
   Effluent PCB concentration 1 ppb. Residence Time -- 365 min.

Figure 3.3.2.1-2

PLOT OF HOUSTON RESEARCH TEST DATA FOR DESTRUCTION OF PCB USING ULTRAVIOLET LIGHT CATALYZED OZONATION



3) Filtration included. Influent PCB concentration 50 ppb. Effluent PCB concentration 10 ppb. Residence Time -- 110 min.

4) Filtration included. Influent PCB concentration 50 ppb. Effluent PCB concentration 1 ppb. Residence Time -- 265 min.

The Houston Research recommendation for the ozone requirement for a waste containing only PCBs is:

1) 4 mg/l O_3 concentration in effluent from reactor.

2) 0.1 mg/l per min. of residence time to account for auto decomposition of O_3.

For waste containing PCB in combination with non-PCB COD, an additional O_3 demand will exist. For the sake of conservatism, it will be assumed that the non-PCB COD must be completely removed before the PCB can be oxidized. It will also be assumed that this can be done within the residence times required for the PCB removal. From "Ozone in Water and Wastewater Treatment" by Evans, an estimate of two to three lbs. of O_3 per lb. of COD was determined. This estimate is thought to be valid at COD concentrations below 50 mg/l. The ratio $\frac{3 \text{ lbs. } O_3}{1 \text{ lb. COD}}$ will be used.

The above parameters were used to develop the following equation:

$$O_3 \text{ lbs/day} = \left| 4 \text{ mg/l} + \left(\frac{.1 \text{ mg/l}}{\text{min.}}\right)(\text{Residence Time (min)}) + \left(\frac{3 \text{ lbs}}{\text{lbs}}\right)(\text{COD (mg/l)}) \right| \times \left| \text{Flow } \frac{(\text{gal})}{\text{min}} \left(1.44 \times 10^{-3} \frac{\text{mgd}}{\text{gpm}}\right)(8.434)\left(\frac{1 \text{ lb } O_3 \text{ produced}}{.7 \text{ lb } O_3 \text{ dissolved}}\right) \right|$$

The estimate of dissolution efficiency of .7 was also arrived at from "Ozone in Water and Wastewater Treatment".

3.3.2.2 Capital Costs

The breakdown of installed capital costs for a UV ozone system are shown for various residence times and COD values in Table 3.3.2.2-1. The system installed costs vs. flow rates are also plotted in Figure 3.3.2.2-1 through Figure 3.3.2.2-4.

Table 3.3.2.2-2 contains total capital costs for the O_3 generator and dissolution equipment. The numbers were furnished by the Union Carbide Corporation for various O_3 production rates. The installed ozonator costs include the generator, air preparation equipment (recycle equipment and O_2 production equipment when O_2 is used as feed gas) and all related systems. The installed dissolution equipment includes spargers, piping blowers, etc. and was estimated at 5% of the installed ozonator costs. Electrical and instrumentation was estimated at 15% of the ozonator and disolution equipment. Recommended building sizes were furnished by Union Carbide and the cost was estimated using $60 per square foot. The total capital was plotted in Figure 3.3.2.2-5 to generate capital costs for all required O_3 production rates.

For production rates in excess of 2000 lbs/day, O_3 was assumed to be the feed gas.

The reactor costs were generated by determining reactor dimensions for the various cases studied. Once the geometry was determined, the cubic yards of excavation was calculated and $5.00 per cubic yard was used. The installed reinforced concrete yardage was determined and a price of $285 per cubic yard used.

The number of UV lamps was determined based on reactor volume and a price of $20 per lamp installed was used. Jack Zeff indicated that the lamps usually cost about $15.

3.3.2.3 Operating Costs

The operating costs for the UV-ozone system are broken down into two parts. The O_3 generation and dissolution power costs shown in Table 3.3.2.3-1 were developed from estimates of installed power in KW supplied by

TABLE 3.3.2.2-1

CAPITAL COST OZONE - U.V. SYSTEM

Reactor Residence (min)	COD mg/1	Flow Q Gal/min	Ozone Prod & Dissolut. lbs/day	Ozone Prod & Dissolut. Cost Instl.	Reactor Installed Vol. ft^3	Reactor Installed Cost Instl.	U.V. Lamps Installed # Lamps	U.V. Lamps Installed Cost Instl.	Total Cost	Total + 10% Engineering
110	30	20	38	50,000	294	8,000	60	1,200	59,200	65,000
		40	74	75,000	588	10,000	120	2,400	87,400	96,000
		80	147	160,000	1,176	13,000	240	4,800	177,800	196,000
		160	294	280,000	2,353	20,000	480	9,400	309,400	340,000
		320	588	510,000	4,706	30,000	940	18,800	558,800	615,000
		640	1176	900,000	9,411	49,000	1880	37,000	986,600	1,085,000
		1280	2352	2,200,000	18,822	80,000	3760	75,200	2,355,200	2,591,000
		1700	3100	2,500,000	24,996	104,000	5000	100,000	2,704,000	2,974,000
	50	20	58	60,000	294	8,000	60	1,200	69,200	76,000
		40	116	100,000	558	10,000	120	2,400	112,400	124,000
		80	231	240,000	1,176	13,000	240	4,800	257,800	284,000
		160	462	420,000	2,353	20,000	480	9,400	449,400	494,000
		320	924	740,000	4,706	30,000	940	18,800	788,800	868,000
		640	1848	1,600,000	9,411	49,000	1880	37,600	1,686,600	1,855,000
		1280	3696	2,600,000	18,822	80,000	3760	75,200	2,755,200	3,031,000
		1700	4871	3,100,000	24,998	104,000	500	100,000	3,304,000	3,634,000
210	30	20	40	50,000	561	10,000	112	2,240	62,240	68,000
		40	81	75,000	1,123	13,000	224	4,480	92,480	102,000
		80	161	160,000	2,246	20,000	450	9,000	189,000	208,000

TABLE 3.3.2.2-1 (Cont'd)

CAPITAL COST OZONE - U.V. SYSTEM

Reactor Residence (min)	COD mg/1	Flow Q Gal/min	Ozone Prod & Dissolut		Reactor Installed		U.V. Lamps Installed		Total Cost	Total + 10% Engineering
			Lbs/day	Cost Instl.	Vol. ft^3	Cost Instl.	# Lamps	Cost Instl.		
		160	332	310,000	4,492	30,000	898	18,000	348,000	383,000
		320	644	550,000	8,983	49,000	1796	35,900	634,900	698,000
		640	1288	990,000	17,967	80,000	3592	71,800	1,141,800	1,256,000
		1280	2576	2,300,000	35,933	136,000	7186	143,700	2,579,700	2,838,000
		1700	3395	2,600,000	47,724	172,000	9544	190,900	2,962,900	3,259,190
	50	20	61	60,000	561	10,000	112	2,240	72,240	79,000
		40	123	140,000	1,123	13,000	224	4,480	157,480	173,000
		80	245	250,000	2,246	20,000	450	9,000	279,000	307,000
		160	490	440,000	4,492	30,000	898	18,000	448,000	493,000
		320	980	780,000	8,983	49,000	1796	35,900	864,900	951,000
		640	1960	1,600,000	17,967	80,000	3592	71,800	1,751,800	1,927,000
		1280	3920	2,800,000	35,933	136,000	7186	143,700	3,079,700	3,388,000
		1700	5166	3,200,000	47,724	172,000	9544	190,900	3,562,900	3,919,000
265	30	20	42	50,000	709	13,200	141	2,900	66,100	73,000
		40	85	80,000	1,417	17,300	282	5,600	102,900	113,000
		80	169	165,000	2,834	24,800	566	11,300	201,100	221,000
		160	339	330,000	5,668	36,100	1134	22,700	388,800	428,000
		320	678	580,000	11,336	57,000	2268	43,400	680,400	748,000
		640	1355	1,000,000	22,672	91,300	4534	90,700	1,182,000	1,300,000
		1280	2710	2,400,000	45,344	156,900	9068	181,400	2,738,300	3,012,000
		1700	3572	2,500,000	60,232	196,100	12046	240,900	2,937,000	3,231,000

TABLE 3.3.2.2-1 (Cont'd)

CAPITAL COST OZONE - U.V. SYSTEM

Reactor Residence (Min)	COD mg/1	Flow Q Gal/min	Ozone Prod & Dissolut lbs/day	Ozone Prod & Dissolut Cost Instl.	Reactor Installed Vol. ft^3	Reactor Installed Cost Instl	U.V. Lamps Installed # Lamps	U.V. Lamps Installed Cost Inst.	Total Cost	Total + 10% Engineering
265	50	20	63	60,000	709	13,200	141	2,900	76,100	84,000
		40	127	140,000	1,417	17,300	282	5,600	162,900	179,000
		80	253	250,000	2,834	24,800	566	11,300	286,100	315,000
		160	507	440,000	5,668	36,100	1134	22,700	498,800	549,000
		320	1014	850,000	11,336	57,000	2268	43,400	950,400	1,045,000
		640	2027	2,100,000	22,672	91,800	4534	90,700	2,510,000	
		1280	4054	2,900,000	45,344	156,900	9068	181,400	3,238,300	3,562,000
		1700	5343	3,200,000	60,232	196,100	12046	240,900	3,637,000	4,001,000

TABLE 3.3.2.2-1 (Cont'd)

CAPITAL COST OZONE - U.V. SYSTEM

Reactor Residence (Min)	COD mg/1	Flow Q Gal/min	Ozone Prod & Dissolut		Reactor Installed		U.V. Lamps Installed		Total Cost	Total + 10% Engineering
			lbs/day	Cost Instl.	Vol. ft	Cost Instl	# Lamps	Cost Inst.		
365	30	20	46	50,000	976	13,200	195	3,900	67,100	74,000
		40	92	100,000	1,952	16,700	390	7,800	124,500	137,000
		80	183	190,000	3,903	27,400	780	15,600	233,000	256,000
		160	367	350,000	7,807	42,700	1560	31,200	423,900	467,000
		320	734	610,000	15,614	68,900	3122	62,400	741,300	815,000
		640	1467	1,100,000	31,228	116,600	6244	124,900	1,341,500	1,476,000
		1280	2934	2,400,000	62,456	203,000	12490	249,800	2,852,800	3,138,000
		1700	3868	2,800,000	82,960	255,000	16592	331,800	3,386,800	3,725,000
	50	20	67	75,000	976	13,200	195	3,900	92,100	101,000
		40	134	150,000	1,952	16,700	390	7,800	174,500	192,000
		80	267	250,000	3,903	27,400	780	15,600	293,000	322,000
		160	535	500,000	7,807	42,700	1560	31,200	573,900	631,000
		320	1070	790,000	15,614	68,900	3122	62,400	921,300	1,013,000
		640	2139	2,100,000	31,288	116,600	6244	124,900	2,341,500	2,576,000
		1280	4278	3,000,000	62,456	203,000	12490	249,800	3,452,800	3,798,000
		1700	5638	3,400,000	82,960	255,000	16592	331,800	3,986,800	4,385,000

Figure 3.3.2.2-1

UV-OZONE SYSTEM INSTALLED COST

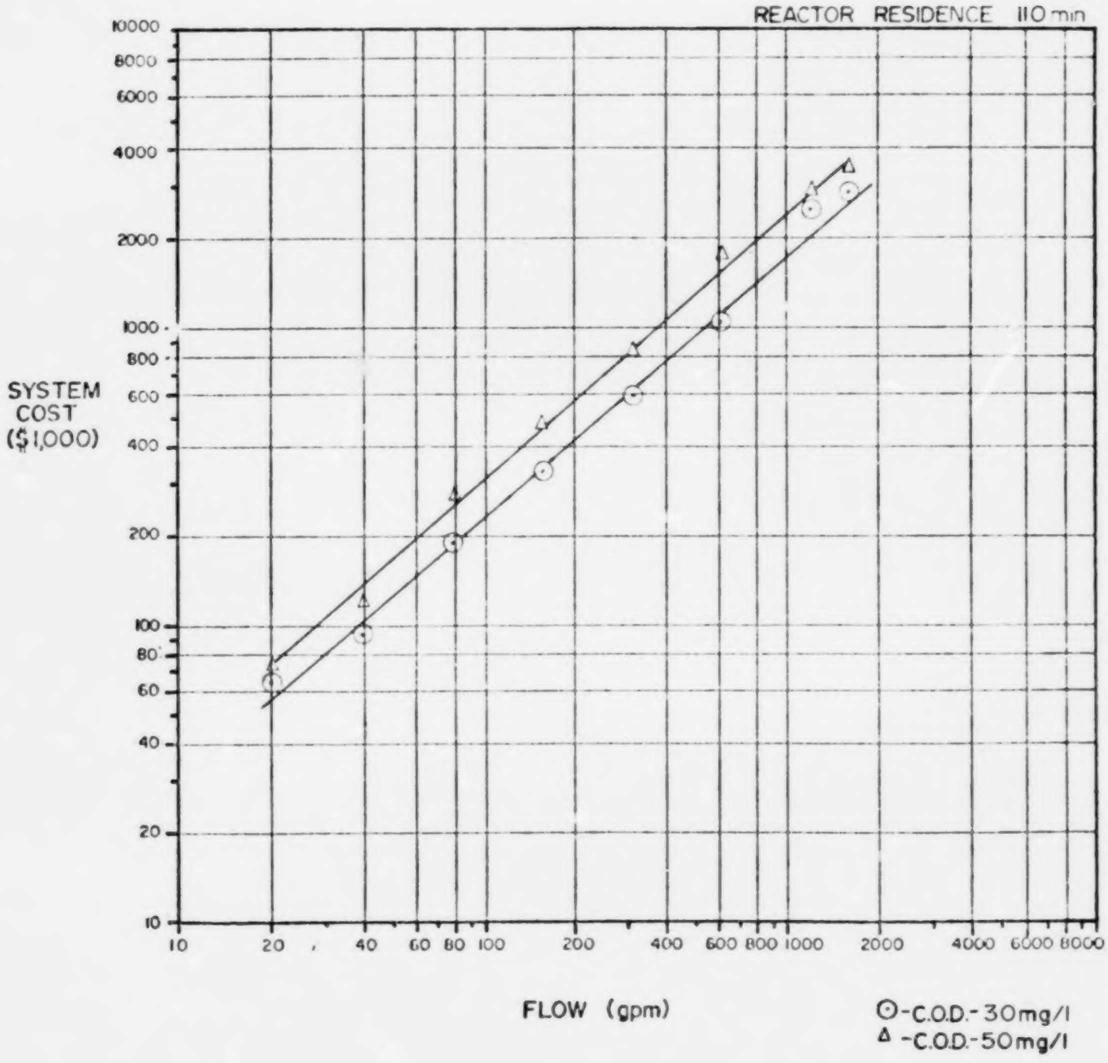


Figure 3.3.2.2-2

UV-OZONE SYSTEM INSTALLED COST

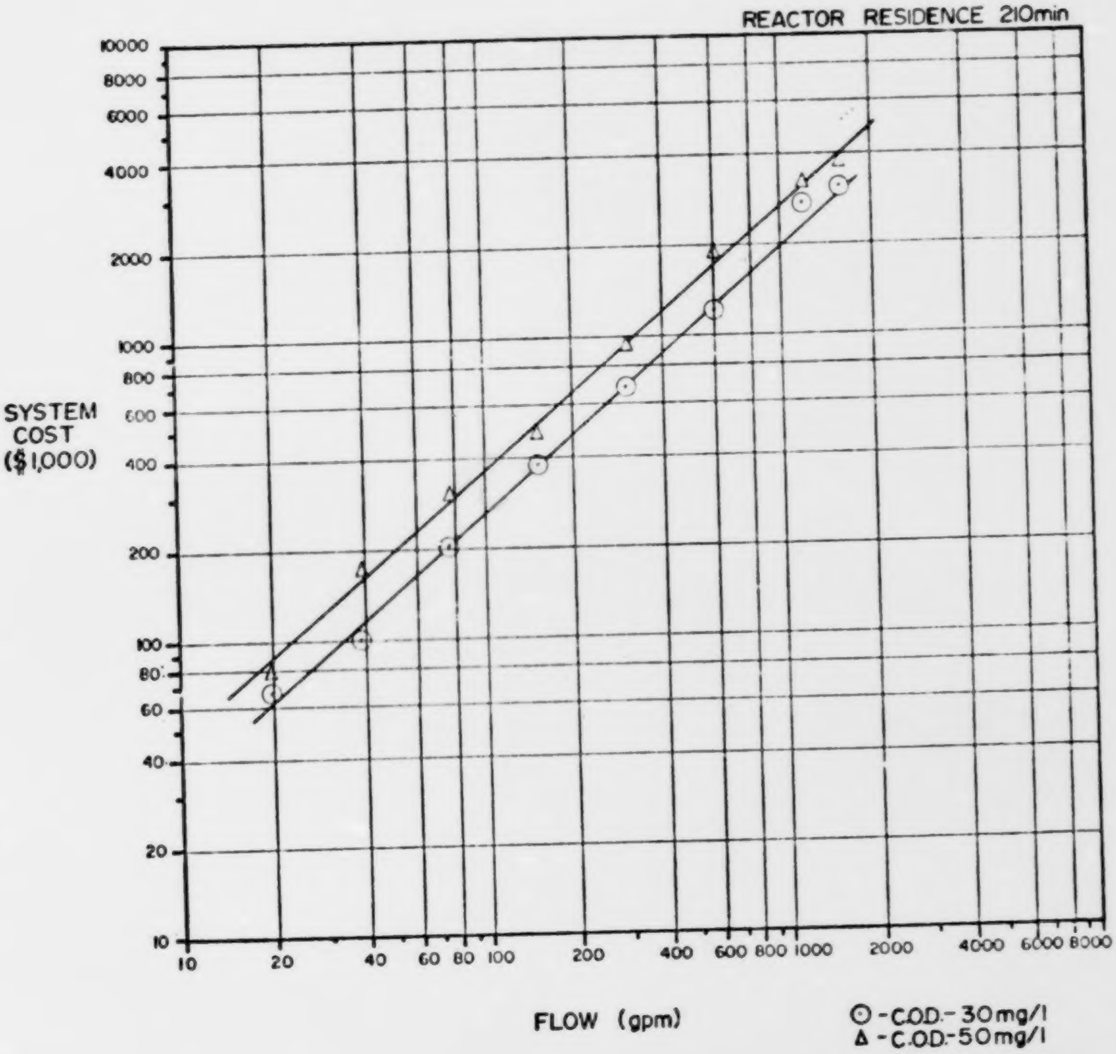


Figure 3.3.2.2-3

UV-OZONE SYSTEM INSTALLED COST

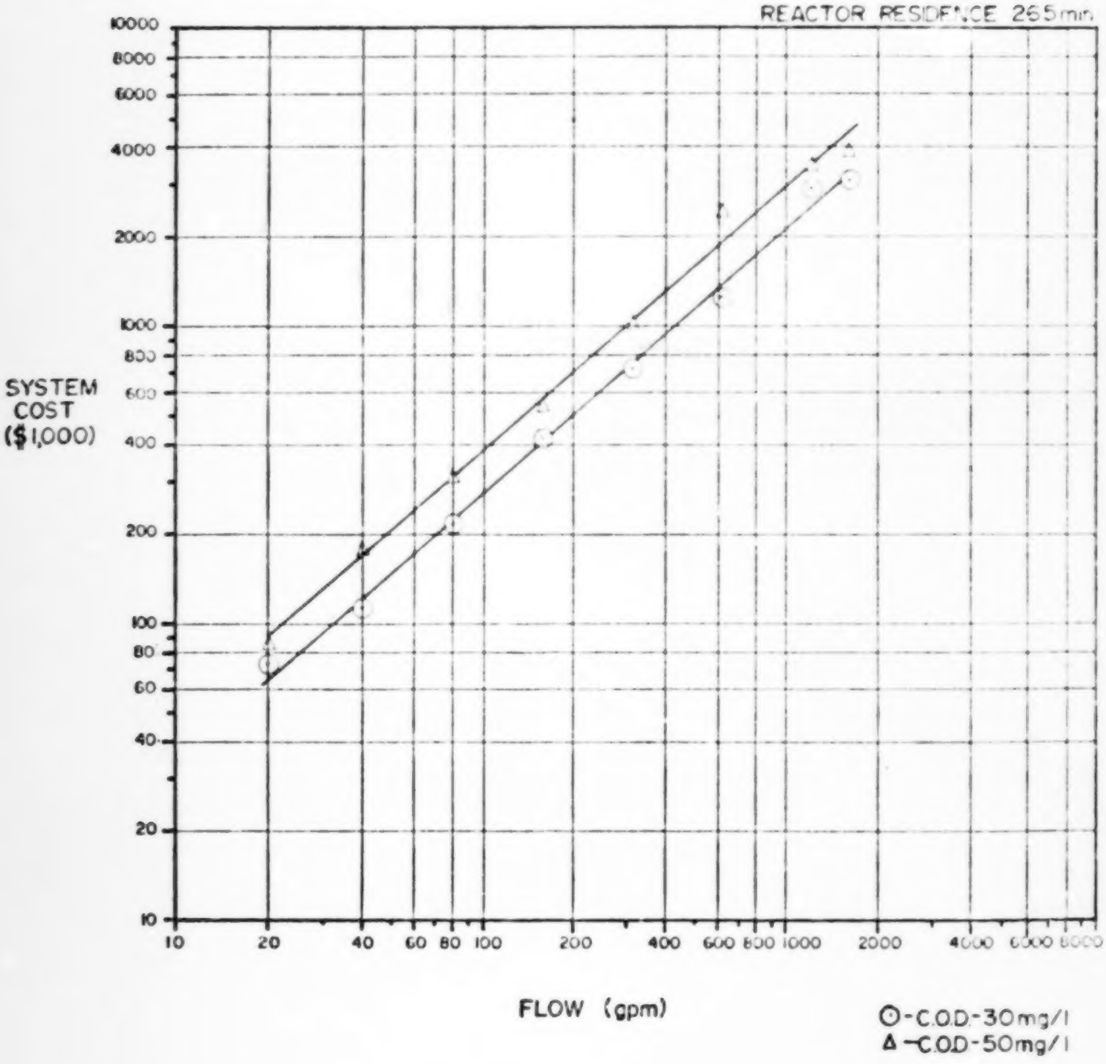


Figure 3.3.2.2-4

UV-OZONE SYSTEM INSTALLED COST

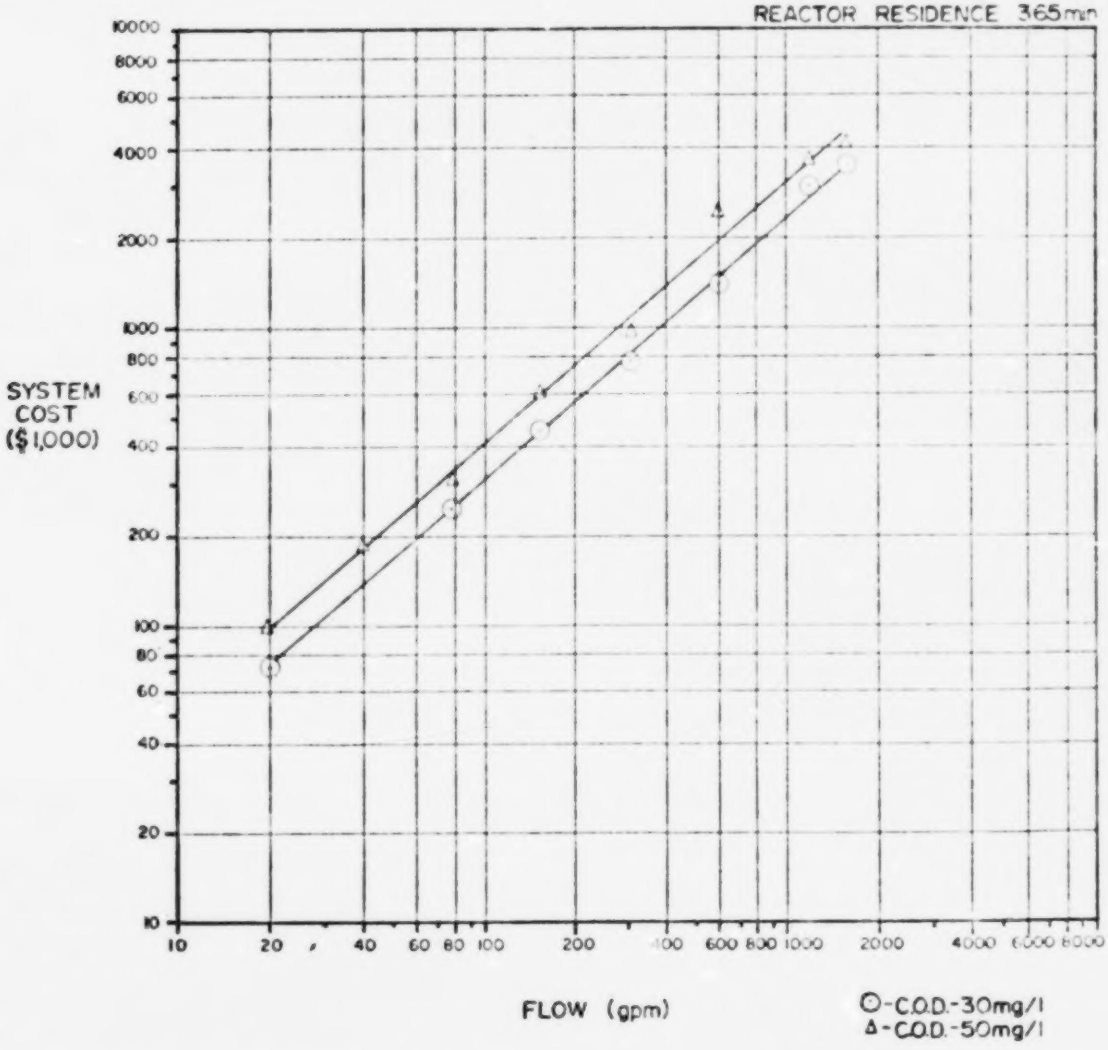


TABLE 3.3.2.2-2

OZONE GENERATION AND DISSOLUTION COST DATA - CAPITAL COSTS

$\frac{\text{lbs. } O_3}{\text{Day}}$	Installed Ozonator	Installed Diss. Equip	Electrical & Instrumentation	Bldg.	Total Cap.
Feed Gas Air					
130	114,000	6,000	18,000	3,800	142,000
260	204,000	10,000	32,000	7,500	254,000
510	372,000	19,000	59,000	15,000	465,000
1020	660,000	33,000	104,000	22,500	820,000
2040	1,200,000	60,000	189,000	30,000	1,479,000
4080	2,224,000	112,000	350,000	45,000	2,731,000
8200	4,176,000	209,000	658,000	75,000	5,118,000
Feed Gas O_2					
2040	1,860,000	93,000	293,000	30,000	2,276,000
4080	2,340,000	117,000	369,000	45,000	2,871,000
8200	3,720,000	186,000	586,000	75,000	4,567,000

Figure 3.3.2.2-5

OZONE PRODUCTION AND DISSOLUTION CAPITAL COSTS

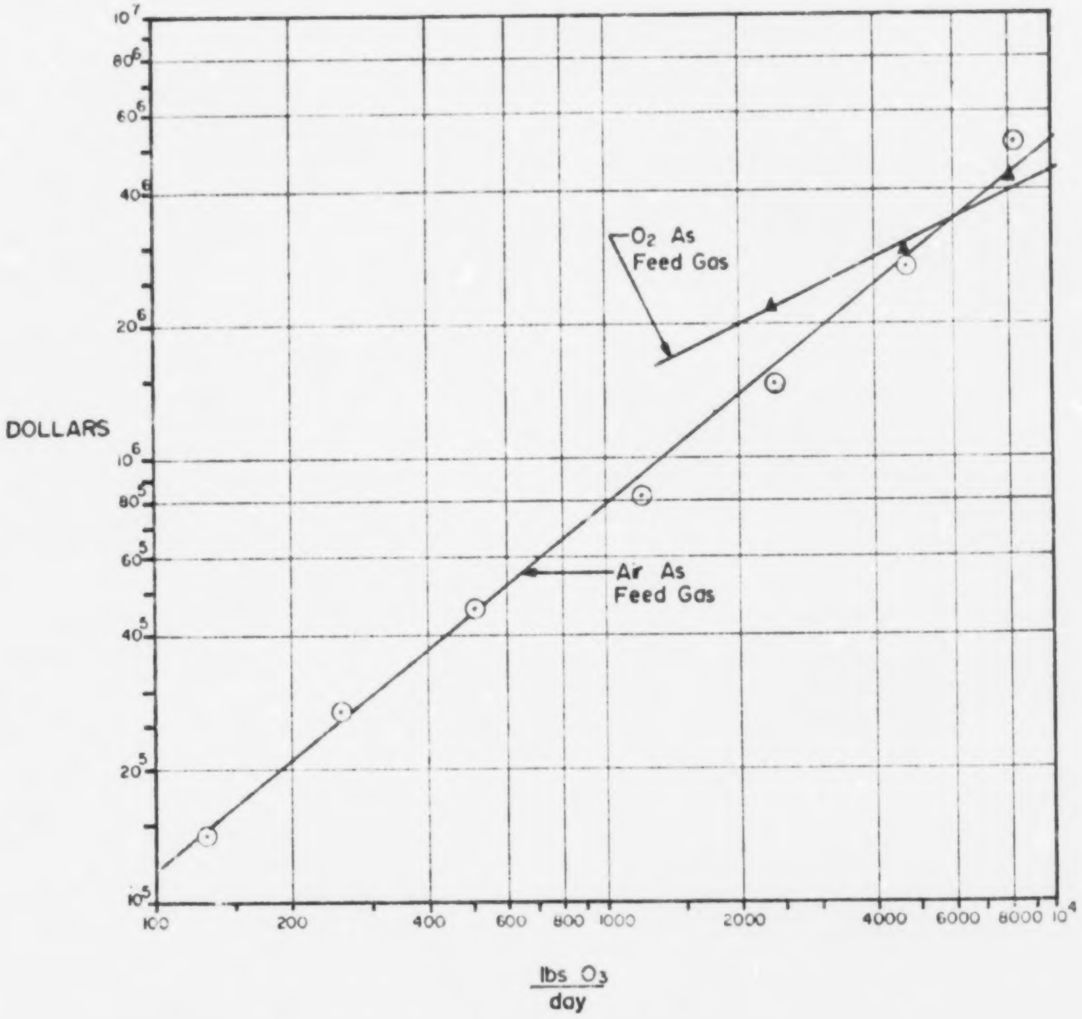


TABLE 3.3.2.3-1

OZONE GENERATION AND DISSOLUTION COST DATA - POWER COST

$\frac{\text{lbs } O_3}{\text{Day}}$	Installed KW	$\frac{\text{KWH } O_3}{\text{Day}}$ Prod	$\frac{\text{KWH } O_3}{\text{Day}}$ Dissolution	Total $\frac{\text{KWH}}{\text{day}}$	$\frac{\text{Cost}}{\text{day}}$ @ $\frac{\$.02}{\text{KWH}}$
Feed Gas Air					
130	64	1536	79	1615	32
260	128	3072	154	3226	65
510	256	6144	307	6451	129
1020	510	12240	612	12852	257
2040	1020	24480	1224	25704	514
4080	2040	48960	2448	51408	1028
8200	4100	98400	4920	103320	2066
Feed Gas O^2					
2040	445	10680	1224	11904	238
4080	880	21120	2448	23568	471
8200	1750	42000	4920	46920	938

Union Carbide for various production rates. The estimate for dissolution power was made by taking 5% of the KW for O_3 generation. A price of $.02 per KWH was used. Costs for all production rates are plotted in Figure 3.3.2.3-1.

The power costs for the UV lamps and the operation and maintenance costs are shown in Table 3.3.2.3-2 for all the conditions studied. Each lamp was rated at .043 KW. For flow rates up to 640 gpd, it is assumed that one man would be required for 24 hours at $15 per hour. For flow rates 640 gpd and above, two men are assumed necessary.

3.3.2.4 Total Treatment System Cost for Zero Discharge System

Because of the very high capital and operating costs associated with the generation of O_3 which is primarily affected by COD and reactor residence time, it is assumed that full scale systems would incorporate filtration before UV-ozone treatment. This would reduce the required residence time as the influent PCB concentration would be reduced to 50 ppb.

Because of the desirability to approach "zero PCB discharge" an effluent concentration of 1 ppb is necessary. Measuring concentrations below 1 ppb is questionable so for the sake of this cost analysis, 1 ppb will be assumed to mean "zero discharge".

The total system cost will be based on the following parameters:

Influent PCB = 50 ppb
Effluent PCB = 1 ppb
Reactor Residence Time = 265 min
Non-PCB COD Conc. = 30 mg/l

The total installed system cost including pretreatment costs to accomplish the above appears in Table 3.3.2.4-1. The total annual operating cost and cost per 1000 gallons are presented in Table 3.3.2.4-2.

3.3.2.5 Total Wastewater Treatment Plant Costs Using Activated Carbon or Ultraviolet Light Catalyzed Ozonation

The costs developed in Sections 3.2, 3.3.1 and 3.3.2 were used to calculate the total treatment system costs. For the activated carbon

FIGURE 3.3.2.3-1

OZONE GENERATION AND DISSOLUTION POWER COSTS

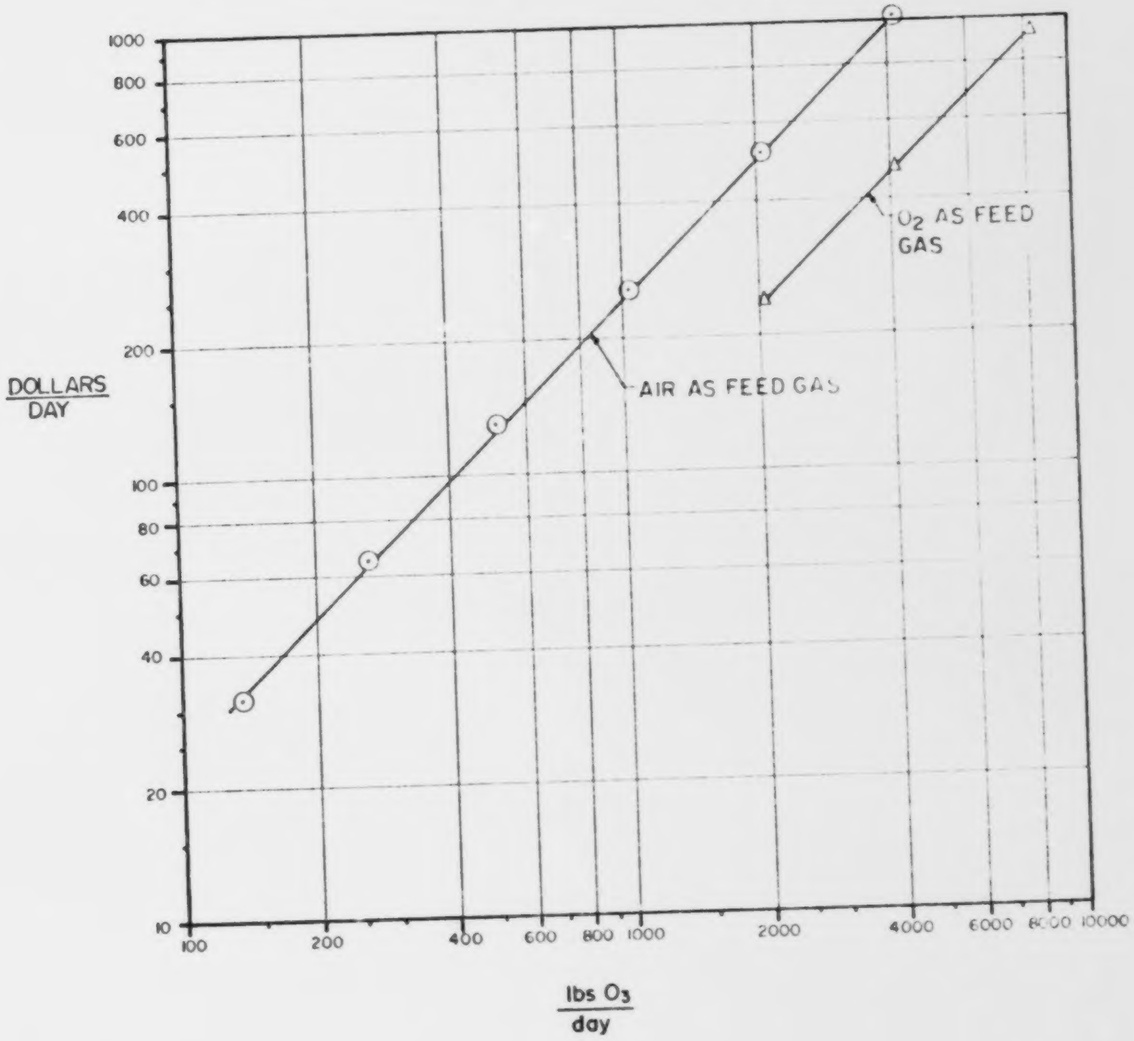


TABLE 3.3.2.3-2

U.V. LIGHT POWER AND SYSTEM MAINTENANCE COST

Residence Time (min)	Flow Gal/day	U.V. Power		Operation & Maint.		Total Cost/day
		KWH/day	Cost/day	# Men	Cost/day	
110	20	62	1	1	360	361
	40	124	2	1	360	362
	80	249	5	1	360	365
	160	495	10	1	360	370
	320	970	19	1	360	379
	640	1940	39	2	720	759
	1280	3880	78	2	720	798
	1700	5160	103	2	720	823
210	20	116	2	1	360	362
	40	232	4	1	360	364
	80	464	8	1	360	368
	160	927	19	1	360	379
	320	1853	37	1	360	397
	640	3707	74	2	720	794
	1280	7416	148	2	720	868
	1700	9849	197	2	720	917
265	20	145	3	1	360	363
	40	290	6	1	360	366
	80	584	12	1	360	372
	160	1170	23	1	360	383
	320	2340	47	1	360	407
	640	4679	94	2	720	814
	1280	9358	187	2	720	907
	1700	12,431	248	2	720	968
365	20	201	4	1	360	364
	40	402	8	1	360	368
	80	804	16	1	360	376
	160	1608	32	1	360	392
	320	3221	64	1	360	424
	640	6444	129	2	720	849
	1280	12,890	258	2	720	978
	1700	17,120	342	2	720	1062

TABLE 3.3.2.4-1

TOTAL INSTALLED SYSTEM COST FOR U.V.-OZONE SYSTEM

($1000)

FLOW (gpm)	20	40	80	160	320	640	1700
Ozone-UV System Installed Including Engineering	73	113	221	428	748	1300	3231
Total Pretreatment Plant Cost	142	198	308	484	821	1463	3699
Total Plant Cost	215	311	529	912	1569	2763	6930

TABLE 3.3.2.4-2

ANNUAL OPERATING COST FOR U.V. OZONE SYSTEM
($1000)

FLOW (gpm)	20	40	80	160	320	640	1700
Total Plant Cost Amortization (8%-10 yr.)	32	46	79	136	234	412	1033
Ozone Generation & Dissolution Power Costs @ $.02/KWH	9	11	17	24	58	110	146
U.V. Light Power @ $.02/KWH and System Maintenance Cost	132	134	136	140	149	297	353
Pretreatment Operation & Maintenance & Power @ $.02/KWH	4	7	10	17	28	49	108
Annual Total Treatment Cost	197	238	322	477	789	1508	3340
Cost/1000 GAL($)	18.7	11.3	7.6	5.7	4.7	4.5	3.7

system, the total installed system cost is given in Table 3.3.2.5-1. The total annual operating cost and cost per 1000 gallons are presented in Table 3.3.2.5-2. Figures 3.3.2.5-1 and 2 graphically depict these costs. Similar information was presented for UV-ozonation in the previous subsection (subsection 3.3.2.4). In each instance, pretreatment was considered necessary so the only variation in cost other than that caused by flow is the difference between the carbon and ozone systems.

To compare the two, a feed stream containing 30 mg/1 COD and 50 ppb of PCB was used for the final treatment section.

Comparing the terminal treatment capital costs of the two systems shows at least a 100% greater cost for the ozone system over the carbon system. When treatment costs are combined with the terminal treatment costs, the UV-ozonation process is about 10 percent higher than the carbon process.

This leads to the recommendation that all efforts be made to reduce flows.

3.3.3 Cost of Implementing Carbon Adsorption Treatment for Selected Plants

Based on the unit operations costs for carbon adsorption and pretreatment operations, including flow equalization, sedimentation/flotation and filtration, capital and total annual costs were projected for selected manufacturing plants. Table 3.3.3-1 presents data for a number of plants based on pretreatment of total plant wastewaters with terminal activated carbon treatment and subsequent discharge to surface waters. Table 3.3.3-2 introduces the alternative of segregating and recycling non-contact cooling water in a closed loop air cooled system, while providing pretreatment and activated carbon treatment for the process and rainwater runoff waters prior to discharge. A comparison of the costs given in the above tables indicates that the capital cost of the complete treatment alternative versus that utilizing segregation of cooling water varies between 1.3 and 4.6, favoring segregation of closed loop cooling water. The total annual costs likewise reflect cost ratios of 1.2 to 3.4 favoring the alternative based on segregating the cooling water in a close loop system.

TABLE 3.3.2.5-1

TOTAL INSTALLED PLANT COST WITH ACTIVATED CARBON ($1000)

FLOW (gpm)	20	40	80	160	320	640	1700
EQUALIZATION BASIN	68	101	159	267	470	856	2080
FILTER SYSTEM	32	40	62	78	120	200	600
CARBON ADSORPTION	32	42	66	86	138	236	708
CARBON REGENERATION	-	-	-	-	180	180	180
DECANT TANK	3	3	3	7	7	7	12
CLEAN WATER RESERVE	7	10	16	19	27	39	39
TOTAL MODULAR COST	142	196	306	457	942	1518	3619
PIPING & INSTRUMENTS (25%)	36	49	77	114	236	380	905
TOTAL CAPITAL COST	178	245	383	571	1178	1898	4524
ENGINEERING (10%)	18	25	38	57	118	190	452
TOTAL PLANT COST	196	270	421	628	1296	1088	4976

TABLE 3.3.2.5-2

TOTAL ANNUAL OPERATING COST FOR PCB REMOVAL FROM WASTEWATER WITH ACTIVATED CARBON ($1000)

FLOW (gpm)	20	40	80	160	320	640	1700
AMORTIZATION (8%-10 yr)	29	40	63	94	166	284	715
CARBON	4	7	14	28	47	70	137
LABOR & MAINTENANCE	14	17	21	28	37	59	139
POWER	-	1	3	5	11	12	59
TOTAL	47	65	101	155	261	425	1050
COST/1000 GAL($)	4.47	3.09	2.40	1.84	1.55	1.26	1.18

FIGURE 3.3.2.5-1 - Carbon System

TOTAL INSTALLED TREATMENT PLANT COST FOR REMOVAL OF PCB FROM WASTEWATER

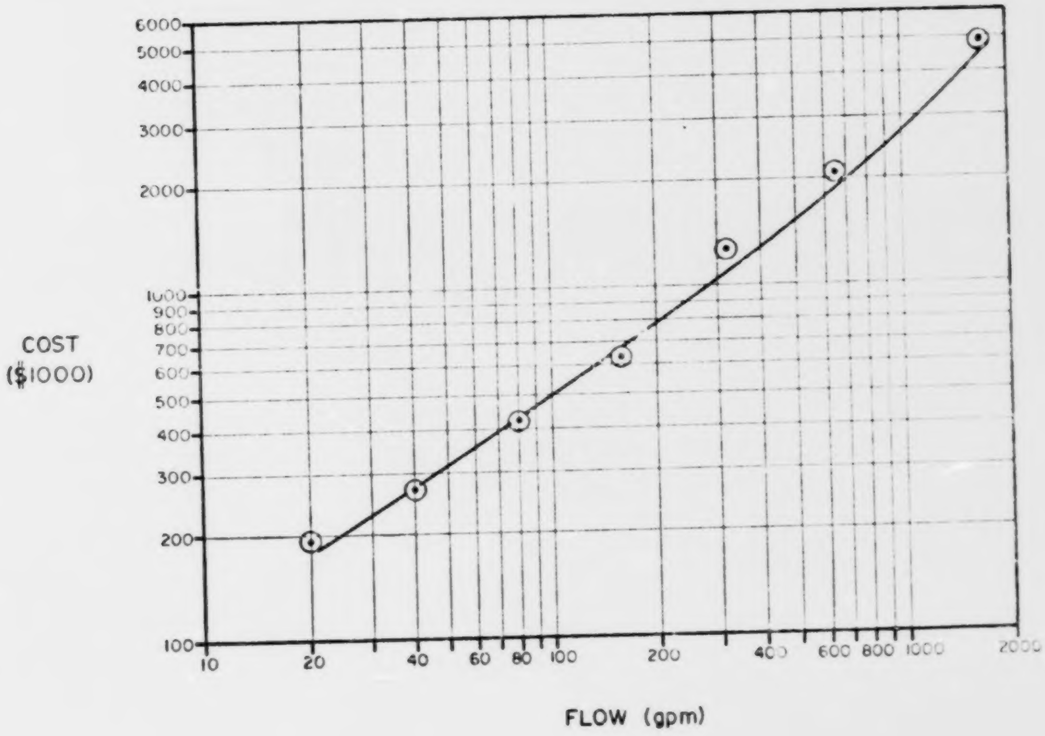
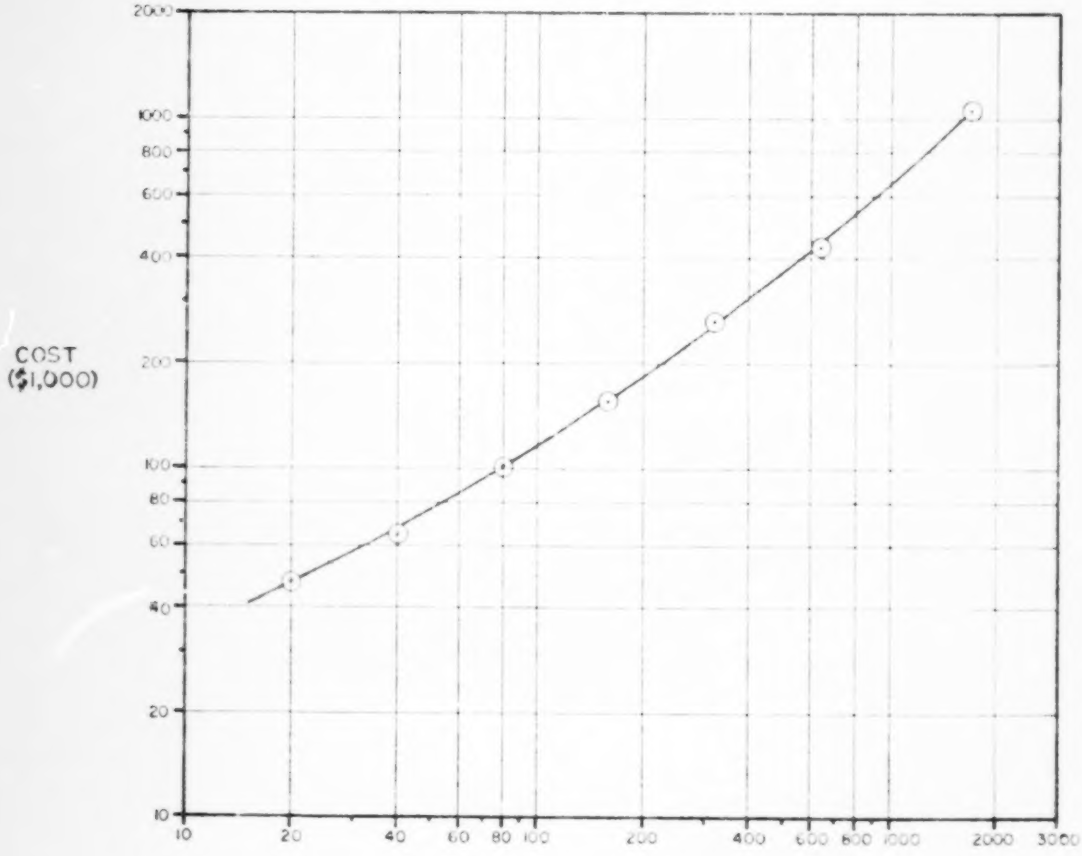


FIGURE 3.3.2.5-2

TOTAL ANNUAL TREATMENT COST FOR REMOVAL OF PCB FROM WASTEWATER USING CARBON AS FINAL TREATMENT



FLOW (gpm)

TABLE 3.3.3-1

COSTS FOR TREATMENT OF ALL FLOWS AND DISCHARGING TO RECEIVING STREAM WITH CARBON FINAL TREATMENT ($1000)

PLANT NO.	100	101	102	103	104	105	106	114
Capital Costs	1700	220	1400	3500	2500	1400	1100	310
Annual Costs	400	57	310	950	600	310	260	73

TABLE 3.3.3-2

COSTS FOR ENCLOSED RECIRCULATION AND COOLING OF NON-CONTACT COOLING WATER AND TREATMENT OF ALL OTHER FLOWS USING CARBON AS FINAL TREATMENT

($1000)

PLANT NO.	100	101	102	103	104	105	106	114
Segregation Costs								
Capital	74	-	43	194	82	69	39	23
Annual	11	-	6	29	12	10	5	3
Dry Cooling Tower Costs								
Capital	70	-	20	190	82	50	28	9
Annual	52	-	11	131	76	34	25	6
Treatment Costs								
Capital	480	220	1000	1100	380	600	470	170
Annual	110	57	250	260	91	145	110	47
Total Costs								
Capital	624	220	1063	1484	544	719	537	202
Annual	173	57	270	420	179	189	140	56

Although segregation of the cooling water in a closed loop system appears to offer economic advantages, site restraints for segregation may prove uneconomical at a particular plant. Therefore, some plants may choose to treat the entire plant water and undergo the maximum costs for treatment.

3.3.4 Zero Discharge

Two alternative systems considered for zero discharge are described below.

1. All plant waters, including rainwater runoff would be pretreated. The portion of the water to be utilized in the plant would be subjected to terminal treatment with carbon for purposes of recycling, while the remaining or excess water would be subjected to incineration in a specially designed system employing natural gas as auxiliary fuel. Incineration would be conducted under conditions which would result in essentially zero aqueous discharge from PCBs producer and users.
2. All non-contact cooling water which accounts for about 90 percent of the water (in most plants) would be segregated and totally recycled. All other waters including rainwater runoffs would be united to a central system for pretreatment. The portion of pretreated water to be utilized in the plant would be treated with carbon and recycled. As in the alternative above, the excess waters would be subjected to incineration.

In both of the above cases non "wash up" sanitary waters are to be handled separately and are not considered in the zero discharge costing. In essence, the alternatives differ only in that non-contact cooling waters are either carbon treated for recycling or segregated in a closed loop cooling system.

3.3.4.1 Description of Dry Cooling Tower

The segregated non-contact cooling water is to be cooled in an air-cooled tower consisting of finned tubes and then recycled.

Forced draft evaporative cooling towers were not considered to avoid the potential for either water to air or air to water contamination with PCBs. In addition, the air cooled system eliminates the need for significant blowdown of potentially contaminated cooling waters.

3.3.4.2 Design Criteria

Air cooled towers are proprietary systems and the design criteria will be left to the vendor. Equations for estimating capital and operating costs for these systems were obtained from the Marley Company.

The incineration system is envisioned to consist of a baffled firebox with auxiliary fuel burners using a two second residence time. Water to be incinerated will be atomized directly into the firebox. No scrubber is suggested since effluent gases should be very low in solids and HCl. The exhaust gases could be used to heat a boiler, but no provision has been made for this. The installation of a heat recovery boiler would reduce the operating cost; however, it is believed that the energy produced, either as high pressure steam or electric power, would be much more than required for the facility. The operating temperature would be 2200°F.

3.3.4.3 Capital Costs

Capital costs for the incineration system were developed on the basis of the size of burn chamber required for the desired residence time. Using a 20% heat loss and 25% excess oxygen, it was estimated that about 300 ft^3 of gases would be exhausted at 2200°F and atmospheric pressure per pound of water fed to the incinerator. Capital costs are presented for both the incinerator and the dry cooling tower in Figures 3.3.4.3-1 and 2 and should be considered only approximate.

3.3.4.4 Operating Costs

The annual costs of incineration are most affected by the quantity of gas required. Cost of gas was assumed to be $0.1083 per 100,000 BTU and the enthalpy of water at 2200°F at 2200 BTU/lb. Annual costs for the dry cooling tower and incineration system are presented in Tables 3.3.4.4-1 and 2.

FIGURE 3.3.4.3-1

INCINERATION COST AS USED FOR ZERO DISCHARGE

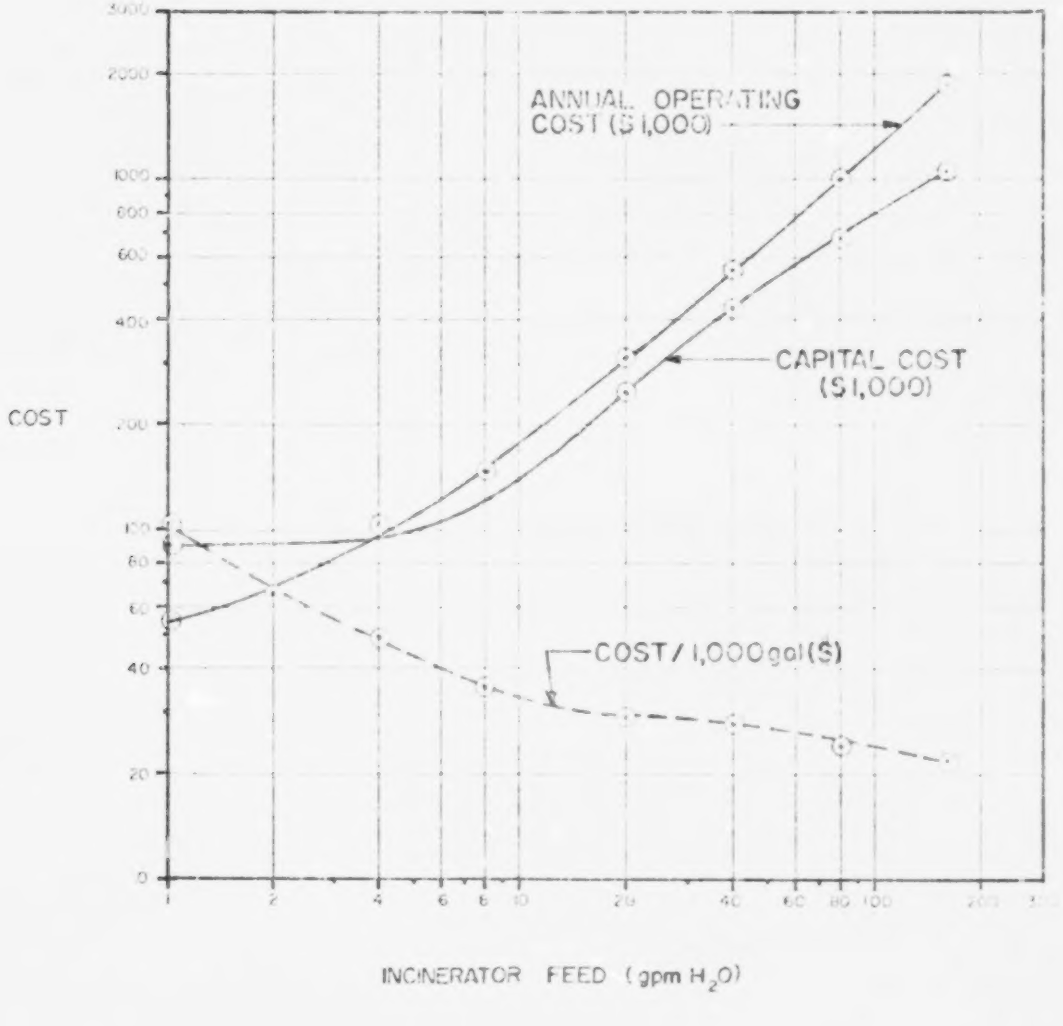


Figure 3.3.4.3-2. COST FOR TOTALLY ENCLOSED COOLING SYSTEM

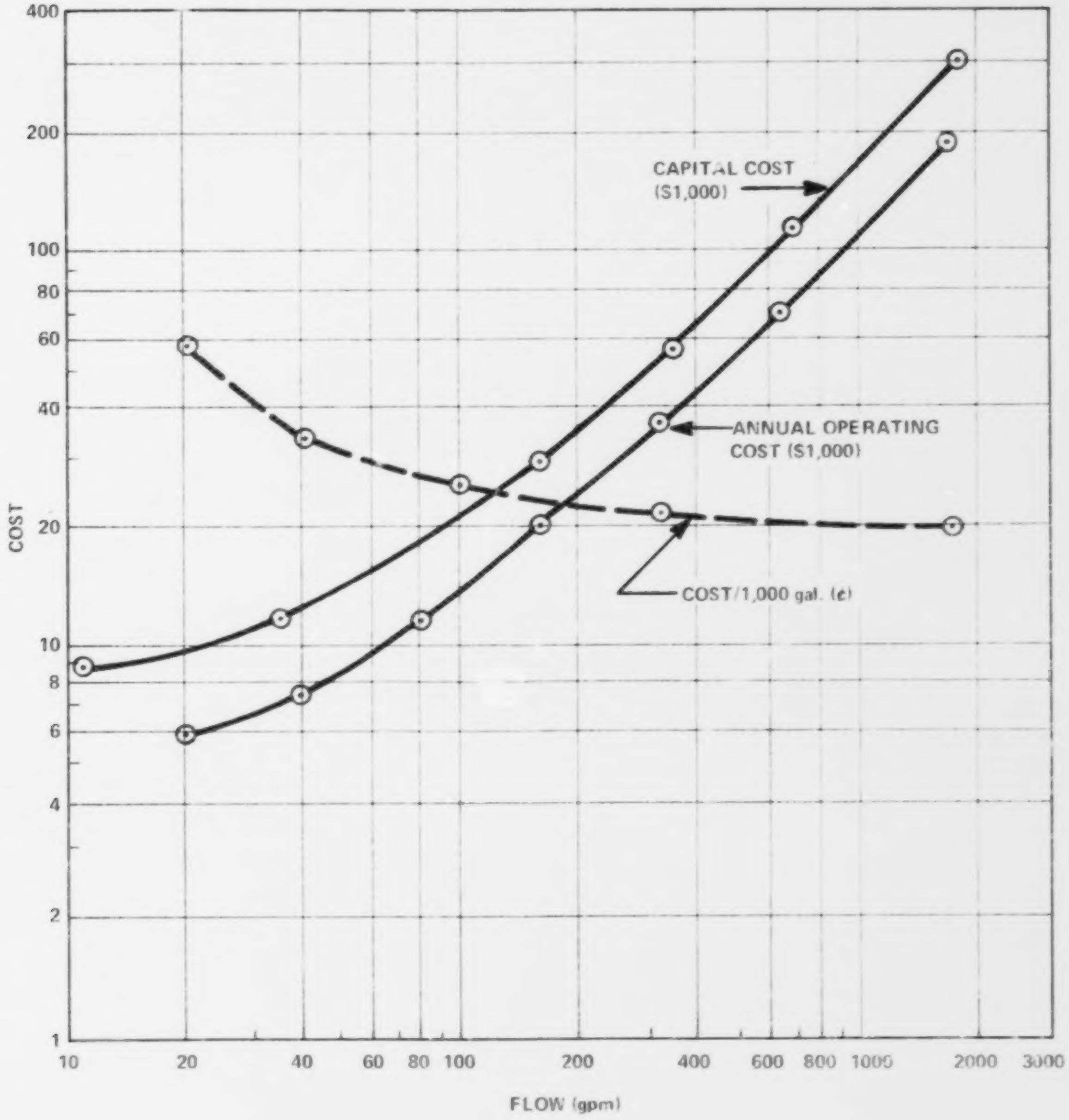


TABLE 3.3.4.4-1

INCINERATOR ANNUAL OPERATING COST
FOR ZERO DISCHARGE METHOD
($1000)

FLOW (gpm)	1	2	4	8	20	40	80	160
AMORTIZATION	13	13	14	18	37	64	101	157
FUEL	10	21	42	84	209	418	836	1640
LABOR AND MAINTENANCE	31	31	47	47	62	62	62	94
TOTAL	54	65	103	149	308	544	1000	1890
COST/1000 GAL ($)	103	62	49	35	29	26	24	22

TABLE 3.3.4.4-2

ANNUAL OPERATING COST FOR TOTALLY ENCLOSED COOLING WATER LOOPS ($1000)

FLOW (gpm)	20	40	80	160	320	640	1700
AMORTIZATION	2	2	3	5	8	15	43
POWER	2	3	6	11	20	37	104
MAINTENANCE (20%)	2	2	3	5	9	17	48
TOTAL	6	7	12	21	37	69	195
COST/1000 GAL (¢)	57	33	29	25	22	21	22

3.3.4.5 Cost of "Zero Discharge" for Selected Plants

The projected capital and total annual costs for selected plants to achieve "zero discharge" are shown in Tables 3.3.4.5-1, 2 and 3. Costs presented in Table 3.3.4.5-1 (carbon treatment of cooling water) and Table 3.3.4.5-2 (closed loop segregation of cooling water) result from the pretreatment of all wastewater including rain water runoff.

The system employing carbon treatment of cooling water for purposes of recycling demonstrates a total annual cost disadvantage ranging from 1.01 to 1.74 times of the annual cost for the system using closed loop segregation of cooling water. However, unique segregation situations may ultimately favor non-segregation for a particular plant.

For comparison purposes Table 3.3.4.5-3 was developed. This table presents the estimated capital and total annual operating cost for the "zero discharge" system (closed loop cooling water) presented in Table 3.3.4.5-2 with the exception that the rainwater runoff is excluded.

For a "zero discharge" system the rainwater contribution is extremely high. Comparison of the above two "zero discharge" cases [(1) inclusion of rainwater runoff as incinerating material and (2) exclusion of rainwater runoff] indicates the annual cost of the case 1 to be 2 to 42 times the cost of the case 2 for the various plants under study.

3.3.5 Comparison of "Zero Discharge" with Discharge to Surface Waters

As mentioned before the least cost "zero discharge" alternative for a number of plants is exhibited in Table 3.3.3-2 while the least cost carbon adsorption system (closed loop cooling water) for the same plants, is exhibited in Table 3.3.4.5-2. The comparison of these two modes of wastewater treatment demonstrates capital cost ratios between 1.1 and 2.3 favoring discharge to waterways. The differences in the annual operating costs for these two modes of treatment are even more pronounced, demonstrating ratios ranging between 1.9 to 11.8 also in favor of discharge to waterways.

TABLE 3.3.4.5-1

COSTS FOR ZERO DISCHARGE

(CARBON TREATMENT OF NON-CONTACT COOLING WATER)

($1000)

Plant No.	100	101	102	103	104	105	106	114
Pretreatment Costs								
Capital	1400	170	1050	3000	2100	1050	820	210
Annual	220	30	170	500	340	170	150	40
Carbon Adsorption Costs								
Capital	210	20	80	500	260	150	120	40
Annual	130	14	48	250	180	85	70	22
Rainwater Incineration Costs								
Capital	140	250	1500	850	280	460	700	140
Annual	165	300	3000	1500	320	610	1000	165
Total Capital Cost	1750	440	2630	4350	2640	1660	1640	390
Total Annual Cost	515	344	3218	2250	840	865	1220	227

TABLE 3.3.4.5-2

COSTS FOR ZERO DISCHARGE (SEGREGATION AND RECYCLE OF NON-CONTACT COOLING WATER) ($1000)

PLANT NO.	100	101	102	103	104	105	106	114
Segregation Costs								
Capital	74	-	43	194	82	69	39	23
Annual	11	-	6	29	12	10	5	3
Dry Cooling Tower Costs								
Capital	70	-	20	190	82	50	28	9
Annual	52	-	11	131	76	34	25	6
Pretreatment Costs								
Capital	330	170	800	830	270	490	330	150
Annual	62	30	145	150	50	88	61	25
Carbon Adsorption Costs								
Captial	62	20	39	110	44	66	21	21
Annual	36	14	22	62	26	39	15	15
Rainwater Incineration Costs								
Capital	140	250	1500	850	280	460	700	140
Annual	165	300	3000	1500	320	610	1000	165
Total Capital Cost	676	440	2445	2174	758	1135	1118	343
Total Annual Cost	326	344	3187	1872	484	781	1106	214

TABLE 3.3.4.5-3

COSTS FOR ZERO DISCHARGE
(SEGREGATION & RECYCLE OF
NON-CONTACT COOLING WATER)
EXCLUDING RAINWATER RUNOFF
($1000)

PLANT NO.	100	101	102	103	104	105	106	114
Segregation Costs								
Capital	74	-	43	194	82	69	39	23
Annual	11	-	6	29	12	10	5	3
Dry Cooling Tower Costs								
Capital	70	-	20	190	82	50	28	9
Annual	50	-	14	131	76	34	25	6
Pretreatment Costs								
Capital	310	110	180	600	210	340	110	110
Annual	59	17	34	120	40	63	17	17
Carbon Adsorption Costs								
Capital	62	20	39	110	44	66	21	21
Annual	36	14	22	62	26	39	15	15
Total Capital Cost	516	130	282	1094	418	525	198	163
Total Annual Cost	158	31	76	342	154	146	62	41

3.4 Scrap Oil Incineration

Based on plant site visits and interviews conducted during this study, data relative to the quantities of liquid PCBs routed to incineration were collected. These data are reported for capacitor and transformer manufacturers in Table 3.2.1.3-2 and in subsection 3.3.1.3 of the Waste Characterization Section (Section IV) of this report. They can be summarized as follows:

Plant Number	Wastes to Incineration lb/ton PCB Used
100	100
101	56
102	98
104	109
105	127
106	300
103	115
114	98
Avg.	125

Based on the data presented in Section IV, Table 3.1.1.1-1, 17,200 tons of PCBs were sold in the domestic market in 1974. Employing the average value of 125 lb. PCBs incinerated per ton PCBs used and the domestic sales of 17,200 tons, it is estimated that 2,150,000 lbs. of PCBs are incinerated annually by the capacitor and transformer manufacturers.

The rationale for estimating costs associated with incineration of PCB contaminated solids and liquid was discussed in Section 2.9. It was determined that a flat rate of $0.10/lb. would be assumed. This cost is at the high end of reported toll incineration charges by commercial disposal firms (reported range $0.05 to $0.10 per lb.). Employing the highest toll charge should reasonable account for transportation and handling charges which are otherwise difficult to evaluate.

At the $0.10/lb. rate, the projected cost to the transformer and capacitor manufacturing industry for scrap oil incineration would be $215,000 per year.

As previously indicated, the only domestic producer of PCBs, Monsanto, has an on-site incinerator with a capacity of six million pounds of PCBs per year. It is reported that a toll of $0.05 per lb. is charged for incineration of PCBs returned to the producer by its customers. It can be reasonably assumed that this is the "breakeven" cost for actual incineration at their facility. Thus the maximum cost per year would be estimated at 6,000,000 lbs. times $0.05/lb. or $300,000. This, of course, would have to be reduced by the amount of toll charges received by Monsanto. Assuming 80% of the total liquid PCBs incinerated by the capacitor and transformer manufacturers are actually returned to Monsanto, the tolls received would be 0.8 x 2,150,000 lb/yr x 0.05 = $86,000. Thus the net annual operating costs for Monsanto's incinerator operation should approximate $214,000 per year.

The total annual cost for scrap oil incineration for the producer and users of PCBs should approximate $429,000 per year.

3.5 Solid Waste Incineration

The data relative to solid wastes (PCB contaminated) generated by the capacitor and transformer industry is very limited. Only three plants reported actual quantities of solids now sent to landfill or incinerated in relation to the amount of PCBs used. These can be summarized as follows:

Plant Number	Solid Wastes lbs/ton PCB Used
100	248
101	129
102	65
Avg	147

Employing the average solid waste generation rate of 147 lbs. per ton PCB used and the domestic PCB sales volume of 17,200 tons per year, the projected pounds of solid wastes to be incinerated per year would be 2,528,000 lb.

Again, assuming an average cost for incineration of $0.10 per pound, the estimated annual cost for solids incineration would be $253,000.

3.6 Total Industry Treatment Costs

The maximum treatment costs for the PCBs users (capacitor and transformer) industries and for PCBs producer (Monsanto) are given in Tables 3.6-1, 3.6-2 and 3.6-3. The costs for the capacitor and transformer industries were developed using the following assumptions.

1. Raw water supply is contaminated with PCB.
2. All groundwater runoff is contaminated with PCB.
3. All non-contact cooling water is contaminated and will be used on a once through basis.
4. Sanitary wastes with the exception of wash water would be discharged to municipality or treated separately as required by State and local ordinances.
5. All process waters will be treated.
6. Incineration charge of $0.10 per pound will be charged for PCB oils and contaminated solids.
7. Pretreatment followed by carbon final treatment and discharge will be used.

Capacitor plants for which data are available as to flows (see Table 3.2.1.3-2 in Section IV) were used to develop costs for this segment of the PCB user industry. These are plants 100, 101, 102, 104, 105 and 106. These are said to be 50% of the capacitor industry. Transformer plants 103 and 114 were used to develop costs for this industry segment and are said to represent 20% of this category. The capacitor industry used 22,000,000 lbs./yr PCBs while the transformer industry used 12,000,000 lbs/yr in 1974. These rates are equivalent to 65 and 35% of the domestic sales , respectively.

TABLE 3.6-1

MAXIMUM CAPACITOR INDUSTRY COST

Capital	$16,600,000
Liquid Incineration	140,000
Solid Incineration	160,000
Annual Wastewater Treatment	3,900,000
Total Annual Cost	$ 4,200,000

TABLE 3.6-2

MAXIMUM TRANSFORMER INDUSTRY COST

Capital	$17,300,000
Liquid Incineration	75,000
Solid Incineration	90,000
Annual Wastewater Treatment	4,650,000
Total Annual Cost	$ 4,815,000

TABLE 3.6-3

COST FOR MONSANTO TREATMENT

Capital	$ 1,600,000
Annual Incineration	214,000
Solid Incineration	11,000
Annual Wastewater Treatment	370,000
Total Annual Cost	$ 595,000

TABLE 3.6-4

MAXIMUM PCB INDUSTRY TREATMENT COST

Capital	$35,500,000
Annual	$ 9,610,000
Cost per Pound PCB Sold	$0.28

Rainwater contribution to the capital and annual wastewater treatment costs was estimated at 15 and 25% respectively. If significant isolation of the contaminated areas can be achieved this will reduce the costs somewhat.

TABLE 3.6-5

MAXIMUM PCB INDUSTRY TREATMENT COST NEGLECTING RAINWATER RUNOFF

Capital	$31,000,000
Annual Incineration	700,000
Annual Wastewater	7,000,000
Total Annual	$ 7,700,000
Cost per Pound PCB Sold	$0.22

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APPENDIX A

Plant 106's Position Statement on Dow's XFS-4169 Capacitor Dielectric Liquid

We believe that the Dow XFS-4169 liquid will be a viable replacement for Polychlorinated Biphenyls in capacitors based on limited tests involving all-film capacitor dielectric systems. These data indicate discharge inception voltage about equivalent to the PCB all-film system and discharge extinction voltages again equivalent to PCB systems. Typically, for a given design, these figures would be:

Discharge Inception Voltage		Discharge Extinction Voltage	
PCB	2.5kv	PCB	2.0kv
XFS-4169	2.75kv	XFS-4169	2.0kv

Another critical electrical characteristic of capacitor dielectric systems is dissipation factor which our tests show typically would be .02% for PCB film systems and .02% for the XFS-4169 liquid film system.

The dielectric constant of the systems also are just about equal as indicated by our test results.

We have completed a number of small sized test units of the XFS-4169 liquid all-film system which are under test. We are continuing our investigation by producing additional small units to investigate the statistical performance of this dielectric system. The initial results indicate satisfactory life performance.

We have also begun construction of full sized prototype units and have a few under test.

At least one year will be required to produce and put into field trial a statistically significant number of full sized units. At that time, we will have reasonable verification of the performance of XFS-4169 liquid all-film capacitor dielectric system.

More extensive testing was done on Dow XFS-4162. The electrical characteristics were very similar to XFS-4169.

1. 100-KVAR prototype units have operated at elevated stress for over two years.
2. Laboratory small sized units have operated at 200% of rated design stress for thousands of hours.
3. Long-term tests on small sized units have been conducted at low and high temperatures and with switching surges.

APPENDIX B

PCB Adsorption Testing by XAD-4 Resin

Experiments and Results

The apparatus and materials used by Rohm and Haas were:

Two glass columns - 1/2" in diameter
Adsorbent volume in each column - 50 mls
Adsorbent bed height in columns:
  XAD-4 AMBERLITE polymeric adsorbent - 16.5"
  Activated carbon (Filtrasorb 300) - 15"
PCB material used - Aroclor 1254 (manufactured by Monsanto)

In the procedure, a feed solution representing a PCB-contaminated waste stream was made up containing around 160 ppb of PCB. Aroclor 1254 is a very viscous material, so it was solubilized in methanol before being dispersed in the water. In order to maintain a constant flow throughout the experimental run, two batches of feed solution had to be prepared. The composition of each feed solution is presented in Table 1. Methanol was used to increase the solubility of PCBs in water.

Table 1

Composition of Feed Solutions

Feed Solution A - 13.25 liter
  0.0022 gm of PCB or 166 ppb
  2 ml of methanol or 119 ppm

Feed Solution B - 13.25 liter
  0.0029 gm of PCB or 218 ppb
  2 ml of methanol or 119 ppm

The influent solution was simultaneously passed through the column of AMBERLITE polymeric adsorbent and activated carbon at a flow rate of 2 bed volumes/hour (0.25 gpm/ft^3 resin). Samples were collected from each column daily; so that each sample nominally represented 48 bed volumes of effluent.

Liquid passed through both columns for five days, or until 240 bed volumes of effluent (12 liter) had been collected from each column.

For analysis, the PCBs in each effluent sample were extracted into a volume of hexane equal to one tenth the volume of the original sample. The influent material was sampled four times during the run, and likewise extracted into the same ratioed amount of hexane. This single stage extraction removed upwards of ninety five percent of the PCBs present in the aqueous sample. The effluent samples were then evaporated to 5 mls of hexane, further concentrating the PCBs present. These PCBs in hexane samples were then sent to Versar, Inc. for analysis, with the results given in Table 2.

Table 2

Reductions of PCBs (Aroclor 1254) Concentrations Through AMBERLITE Polymeric Adsorbents and Activated Carbon

Day	Nominal Throughput (BV)	Influent Concentration (ppb)	Effluent Concentration (ppb)	
			AMBERLITE Adsorbent	Carbon
1	1-48	25 (Feed A)	0.246	0.050
2	49-96	none detected	0.031	0.055
3	97-144	21.1 (Feed B)	0.023	0.025
4	145-192	0.69	none detected	none detected
5	193-240	0.69	3.470	0.045

A significant amount of PCBs was adsorbed onto the walls of the influent container. Sample A, for example was prepared with 166 ppb of PCBs. This loss by adsorption on equipment surfaces has been also detected in other tests, and must be provided for.

Both AMBERLITE polymeric adsorbent and activated carbon reduced the concentration of PCBs in water to less than 0.05 ppb. The higher leakage of material for the first day's passage of effluent could be due to an incomplete conditioning of the resin beads, and some material leaching out of the resin. The high value of leakage for the last sample from the polymeric adsorbent must be viewed with some suspicion, especially since it indicates a leakage of PCB higher than that in the influent.

AMBERLITE polymeric absorbents are usually solvent regenerated. This is because the energy of adsorption is much higher for activated carbon than it is for these resins. Hence adsorbed solute can be removed simply by passing a solvent through the resin whose solvent-adsorbed solute extraction can overcome the Van der Waals forces. Carbon requires a more energy intensive process of regeneration, such as thermal rejuvenation. Work performed by Musty and Nickles (J. Chromat., 89:185 (1974)) with PCBs and a solution of 10% diethyl ether in hexane as a regenerant indicates that 76 percent of adsorbed PCBs on an AMERLITE polymeric adsorbent can be recovered in the mixed solvent. Undoubtedly, a more efficient solvent could be found that could quantitatively remove PCBs from polymeric adsorbents. Generally Rohm and Haas has found that simple alcohols or ketones are effective solvents for these resins.

The ability to solvent regenerate AMBERLITE polymeric adsorbents in situ would provide the advantage of generating only the more-readily-handled-by incineration liquid phase PCBs wastes.

APPENDIX C

Description of Macroreticular Resins from Rohm and Haas Co.

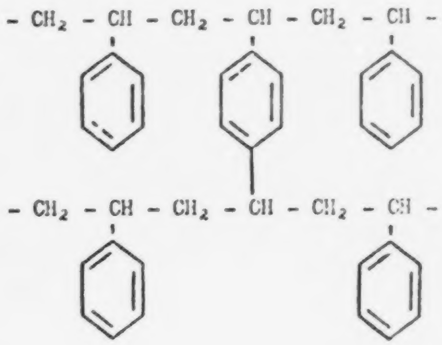
Ion exchange resins have the capability to selectively recover ionic constituents, both inorganic and organic, from water by an ion exchange phenonenon. Organic compounds are often exchanged or adsorbed irreversibly onto an ion exchange resin. This may cause a decrease in capacity so that the operating life is diminished. The more recently developed macroreticular type of ion exchange resins are polymeric adsorbents that are used specifically for adsorbing aromatic and aliphatic compounds from water.

Structures

The macroreticular structures are characterized by having unusually large surface areas as compared with those of conventional gel structures.

Using the newer macroreticular polymerization technique, it is possible to vary widely the particle pore size, pore size distribution, and surface area. Polymers with very small pores (50 Angstroms or less) and high surface areas (in the range of 800 square meters per gram) can be prepared. At the other end of the spectrum, pore sizes in the range of 300,000 Angstroms, which are visible under modest magnification, are possible.

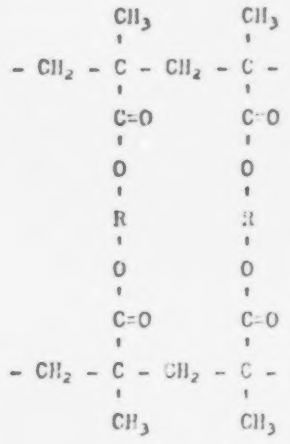
The macroreticular polymerization technique is applicable to a wide variety of monomers. It is possible to introduce functional groups onto the surface of the pre-formed macroreticular polymers. Thus, a great range of surface types is possible limited only by the availability of monomers or the applicability of reactions to introduce functionality. The full line of macroreticular adsorbents includes a spectrum of surfaces from the least polar to the most polar. For PCBs removal, the non-polar and intermediate polarity adsorbents should be best. The chemical structure of AMBERLITE XAD-2 and AMBERLITE XAD-4 in Figure 1 is representative of the non-polar adsorbent series Figure 2 shows the acrylic-ester composition of AMBERLITE XAD-7 and AMBERLITE XAD-8, the intermediate polarity adsorbents.



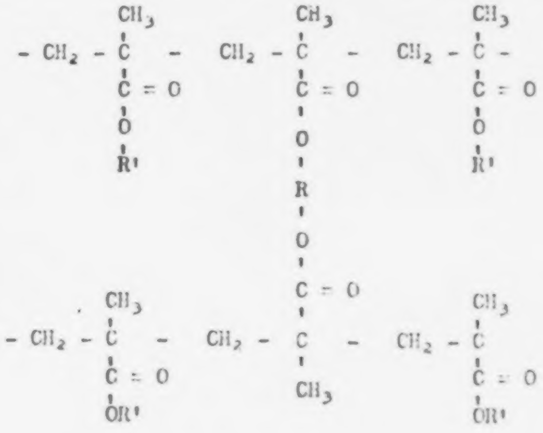
- CH₂ - CH - CH₂ - CH - CH₂ - CH -
- CH₂ - CH - CH₂ - CH - CH₂ - CH -

Structure of Amberlite XAD-2 and Amberlite XAD-4

Figure 1



Structure of Amberlite XAD-7



Structure of Amberlite XAD-8

Figure 2

The physical properties of these AMBERLITE XAD adsorbents are summarized in Table 1.

TABLE 1

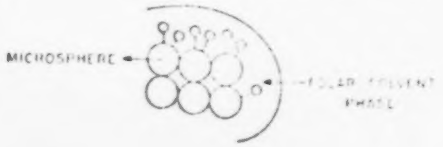
TYPICAL PROPERTIES OF AMBERLITE POLYMERIC ADSORBENTS

	Chemical Nature	Helium Porosity		Surface Area m²/gram	Average Pore Dia Angstroms	Skeletal Density grams/cc	Nominal Mesh Sizes
		Volume %	cc/gram				
			Nonpolar				
XAD 1	Polystyrene	37	0.69	100	200	1.06	20 to 50
XAD 2	Polystyrene	42	0.69	330	90	1.08	20 to 50
XAD 4	Polystyrene	51	0.99	750	50	1.09	20 to 50
			Intermediate Polarity				
XAD 7	Acrylic Ester	55	1.08	450	80	1.25	20 to 50
XAD 8	Acrylic Ester	52	0.82	140	250	1.26	25 to 50

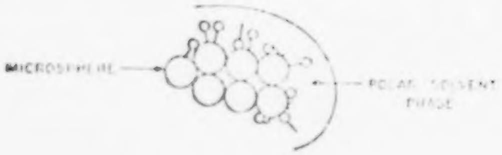
Macroreticular Adsorption Phenomena

An important aspect of the AMBERLITE adsorbents is the nature of the different surfaces. The phenomenon of adsorption on solids involves van der Waals' forces which bind the adsorbate to a solid surface. Many types of interaction such as hydrophobic bonding, dipole-dipole interaction and hydrogen bonding are important. It is not possible to predict accurately just which materials will be adsorbed well by a given adsorbent; however, from a practical point of view, the general concept that hydrophobic or nonpolar molecules or portions of molecules are attracted to hydrophobic surfaces and hydrophilic or polar materials to hydrophilic or polar surfaces is a useful concept. Pictorial views of these interactions are presented in Figure 3. If each organic molecule is thought of as having both a hydrophobic and a hydrophilic end, then the hydrophobic end will be attracted to hydrophobic adsorbents such as AMBERLITE XAD-2 and AMBERLITE XAD-4. This is particularly true when the adsorption takes place from aqueous solution.

SORPTION ON AROMATIC SORBENTS FROM POLAR SOLUTIONS


MICROSPHERE
POLAR SOLVENT PHASE

SORPTION ON ALIPHATIC SORBENTS FROM POLAR SOLUTIONS


MICROSPHERE
POLAR SOLVENT PHASE

SORPTION ON ALIPHATIC SORBENTS FROM NON-POLAR SOLVENTS

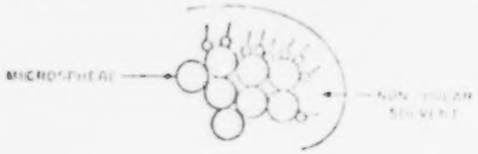

MICROSPHERE
NON-POLAR SOLVENT

Figure 3

For PCBs, it would be expected that the biphenyl portion would be typically aromatic and hydrophobic, and attracted to the aromatic resin. Increasing chlorination reduces the water solubility of both benzenes and biphenyls, and thus would not be contributing anything to what little polar character the PCBs might have. Thus, the PCBs would not have any "polar end" as shown in the figure, like a sulfonated aromatic, but would be strongly repelled by the water phase, and strongly attracted by the resin.

A recent study by Dr. James Fritz, et al, of Iowa State University, reported a method for extracting trace organic contaminants from water using macroreticular resins. He also demonstrated the feasibility of selective desorption using appropriate eluants so that the organics could be identified. He also established the performance or retention efficiency in isolating these compounds. A summary of these laboratory results is tabulated below:

Adsorbent: AMBERLITE XAD-2 unless otherwise indicated
Particle Size: 100 - 150 mesh
Flow Rate: 10 BV/hr. (1.25 gpm/cu. ft.)

Test Compounds	Influent	Effluent	Retention Efficiency, %
Benzene	100	0	100
Benzene sulforic acid	3.0	2.1	31
Phenol	0.4	0.22	45
Phenol (AMBERLITE XAD-7)	0.4	0.06	86
Aniline (AMBERLITE XAD-7)	4.0	0	100
Naphthalene	0.05	0	100

It can be seen that AMBERLITE XAD-2 and AMBERLITE XAD-7 were most efficient for recovering the nonionic organic compounds with 100% efficiency. These results predict good success with PCBs adsorption. On the other hand, ionic solutes as well as strongly ionized compounds such as benzene sulfonic acids, p-toluene sulfonic acids, etc. were not retained with the same efficiency. It was noted that retention efficiency increases with increasing molecular weight in a homologous series. This would indicate that the higher chlorinated PCBs would be the best adsorbed.

APPENDIX D

Non-Carbon Adsorbtion and Other Research Stage PCB Treatment Technologies

1.0 POLYVINYL CHLORIDE AND POLYURETHANE FOAMS

Dr. John Lawrence and co-workers of Environment Canada have reported on preliminary tests with these polymers, and with carbon and the XAD resins for removal of PCBs from synthetic waste water solutions and from actual raw sewage.

H. D. Gesser in Analytical Letters (12:883 (1971)), reported that a polyurethane foam column quantitatively adsorbs PCBs from water. Lawrence found the carbons, polyurethane foams and the XAD-2 strongly adsorbed PCBs from aqueous solutions, but were much less effective in raw sewage. He found that thw PVC, however, was very effective in removing PCBs from raw sewage.

The following were his test procedures and results. Dr. Lawrence is the only investigator known to have worked with PVC, and the comparative data on the other materials may be used to relate these studies to those in other sections of this report.

1.1 Experimental Method for PCBs Adsorption Tests by Environment Canada

The two stock solutions of Aroclor 1242 and 1254 were prepared by vigorously mixing an excess of each Aroclor with water for eight hours, allowing the solutions to stand overnight and carefully decanting off the true aqueous phase. The water used was double distilled, the second distillation being from an all-glass system. The concentration of these solutions determined by gas chromatography was 45 ± 10 ppb which is consistent with the published solubility for Aroclor 1254 of 56 ppb.

All solvents used were glass distilled pesticide grade (Caledon Laboratories Inc.). The activated carbons employed were lignite based hydrodarco 400 (ICI-United States) and anthracite based Filtrasorb 400 (Calgon Corporation). These were pretreated by heating to 300°C for 12 hours, cooling and twice extracting each 500 gm with 2 liters of hexane. The extracted carbon was then filtered and air dried. The polyurethane foams used were DiSPo plugs (Canlab Supplies Ltd.) and Foams 1115 and 2328 (B.F. Goodrich Ltd.). The first two digits relate to the density, i.e., 1.1 and 2.3 lb/ft^3 and the second two to the hardness. The foams were shredded and successively washed with n-hexane (several times), acetone and distilled water. They were then air-dried. The pretreatment was developed to remove trace organic contaminants from the surface of the foams. The macroreticular polystyrene resins AMBERLITE XAD-2 and XAD-4 (Rohm and Haas Company) were pretreated by successively washing each 500 gm of resin with one liter batches of water, methanol, and water. The cleaned resins were stored in sealed glass containers under methanol to prevent them from drying out. Polyvinyl chloride chips (Monsanto Company) were washed several times with n-hexane and air dried.

To determine the adsorption characteristics, 100-ml aliquots of stock Aroclor solutions were stirred rapidly with weighed amounts of adsorbent for 30 minutes and the adsorbent removed by filtration through a Millipore prefilter pad. Five milliliters of n-hexane were then vigorously stirred with the filtrate for 45 minutes and the organic extract withdrawn. These extracts were analyzed with a gas chromatograph (Varian series) equipped with an electron-capture detector (Ni^{63}). The gas column (1.8m x 1.5 mm i.d.) was packed with 4% OV-101 and 6% OV-210 on Chromosorb W HP $^{80}/_{100}$ mesh. Nitrogen was used as a carrier gas at 50 ml/min. The injection port, column and detector temperatures were 250°C, 200°C, and 300°C respectively. Extraction and analysis of water samples spiked with known amounts of Aroclor indicated that greater than 98% of the PCBs were detected by this method.

Wastewater was collected from the Hamilton Sewage Treatment plant at the raw sewage inlet pipe. Sampling was carried out using all glass containers to insure against adsorption onto container walls. The samples were stored at a constant temperature of 3°C and in all cases were treated and/or extracted within 24 hours of collection. In the evaluation of PCB adsorption from sewage, the procedure described previously for pure Aroclor solutions was followed except that 100 ml samples of raw sewage were stirred vigorously with the adsorbent for one hour and the adsorbent separated by filtration through a 60 mesh, stainless-steel screen. After washing, the screen did not retain any raw sewage and, with the exception of activated carbon, 100% separation of adsorbent was achieved. The samples were then twice extracted with 50 ml of n-hexane in 500 ml separatory funnels. The aqueous portion was discarded and the organic phase, after being dried through 15 g of Na_2SO_4 was reduced to approximately 3 ml using a rotary evaporator. The sample was purified by liquid-solid chromatography on a florisil support column using petroleum ether to elute the PCB fraction and then the eluate was evaporated to 3 ml. Prior to injecting the sample into the gas chromatograph, it was shaken with 0.2 ml mercury to remove residual sulfur compounds.

The PCBs in the samples were identified by comparison with chromatograms of standard Aroclors. The total concentrations of PCB in raw sewage usually averaged 9.8 ± 4 ppb.

1.2 Experimental Results of PCBs Adsorption from Sewage and Synthetic Wastewater

Adsorption data for Aroclor 1254 and 1242 on PVC, activated lignite carbon, anthracite carbon, two polyurethane foams, AMBERLITE XAD-2 and XAD-4 are shown in log-log form in Figure 1.2-1. The weight of PCB adsorbed per unit weight of adsorbent is expressed as a function of the equilibrium concentration of PCB remaining in solution. The sets of data do not follow any of the common isotherm expressions (e.g., Langmuir, Freundlich, BET), and consequently a theoretical interpretation of the results has not been attempted. It is evident that the two carbons and XAD-2 have the greatest adsorption capacities but a residual concentration of less than 3 ppb could not be obtained with lignite carbon. Both polyurethane foams appear to be good adsorbers with relatively high adsorption capacities and low residual levels. DiSPo polyurethane foam plugs were also evaluated but these had identical adsorption properties to the Goodrich foam 1115. The lower efficiency of XAD-4 is surprising in view of the similarity between XAD-2 and XAD-4 (they differ only in pore diameters: 90 Å for XAD-2 and 50 A for XAD-4). The lower efficiency of PVC can be explained by the lower surface area of this adsorbent. The surface area per unit weight is reported as 500-2000 m^2 gm^{-1} for carbon; 750 m^2 gm^{-1} for XAD-4 and 330 m^2 gm^{-1} for

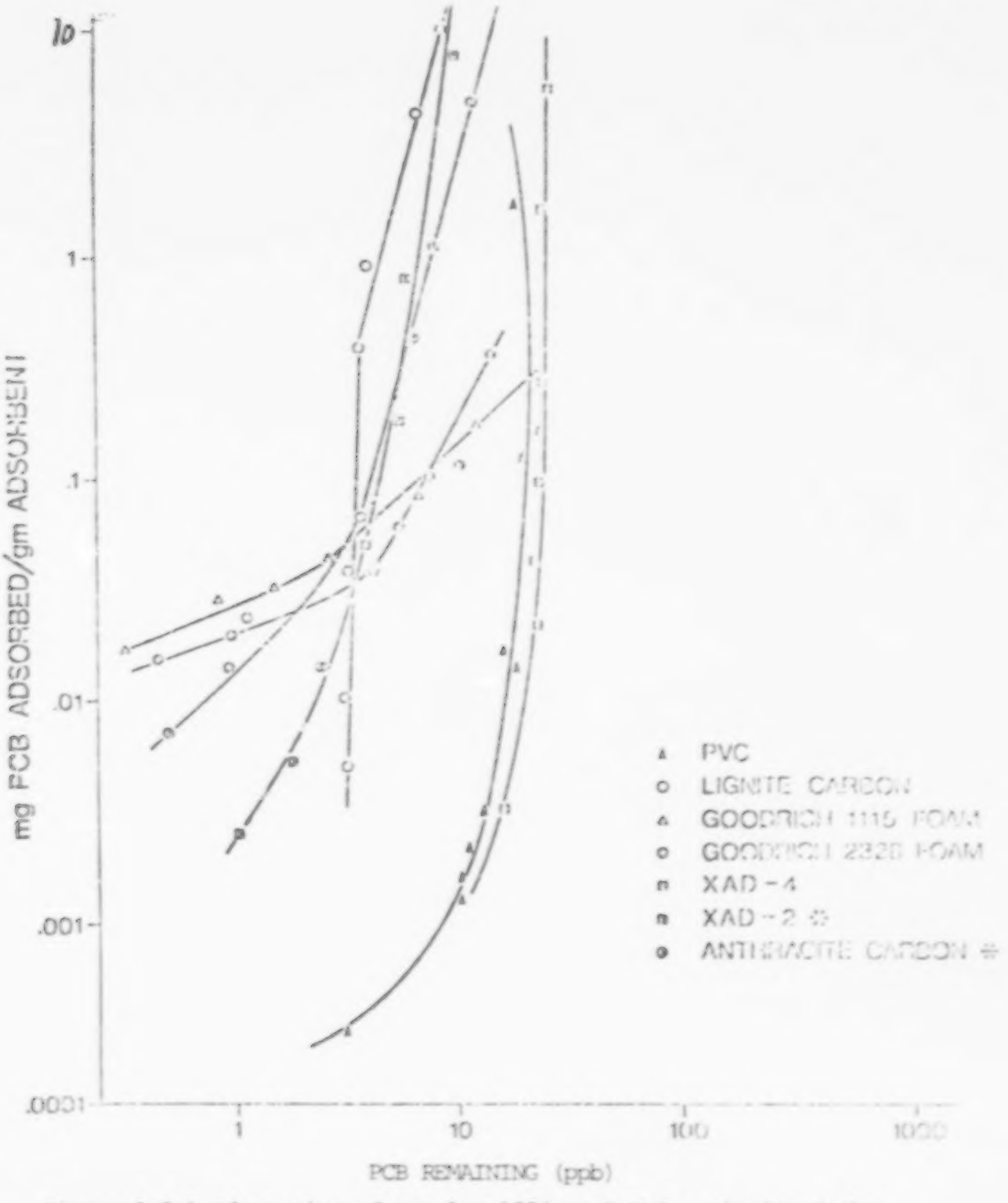


Figure 1.2-1.Adsorption of Aroclor 1254 on P.V.C., Lignite Carbon, Anthracite Carbon, Polyurethane Foams and AMBERLITE XAD-2 and XAD-4.

* Indicates adsorption of Aroclor 1242 rather than 1254

XAD-2 but only 2×10^{-3} m^2 gm^{-1}, for PVC chips - there being no macroreticular structure in PVC. This gives an area ratio XAD-2/PVC of approximately 10^5.

There are two complicating conditions associated with adsorbing PCBs from raw sewage rather than from synthetic aqueous solution: (a) sewage contains other hydrophobic organic matter which competes for the active sites on the adsorbent and (b) much of the PCB has already adsorbed onto the suspended solids by the time the sewage reaches the treatment plant. Condition (b) can easily be demonstrated by filtering raw sewage and monitoring the change in PCB concentration. With typical raw sewage containing 10 ppb PCB, vacuum filtration through a Millipore prefilter pad resulted in the removal of about 75%. It is therefore necessary to find an adsorbent which is not only relatively specific to PCBs, but which also has sufficient affinity for the PCBs such that the PCB-suspended-solid equilibrium is reversed.

Table 1.2-1 shows the percentage of PCB (including both Aroclor 1254 and 1260) adsorbed from raw sewage by five different media. With the exception of the PVC, approximately 1 gm of each media was stirred with 200 ml of raw sewage for 45 minutes; approximately 10 gm PVC were used because of the lower surface area. To minimize the inconsistency of raw sewage, the data have been averaged over several determinations on different days and with different samples of sewage. The data indicate that PVC and XAD-4 are more effective than carbon or polyurethane foams in terms of percentage of PCB removed from raw sewage. This is somewhat surprising since the graphs for PCB adsorption for pure Aroclor solutions (Figure 1.2-1) would predict the opposite to be true. Lawrence believes the likely reasons for this apparent anomaly are: (a) the active sites on carbon are preferentially occupied by hydrophobic species in sewage other than PCBs and (b) suspended solids adhere to the surface of carbon and foam acting as a barrier to further adsorption.

The above results indicate that PVC is superior to the other media for removing PCBs from sewage.

The work at Dr. Lawrence's laboratory is continuing, with studies of methods of scale-up and continuous or multistage operations with PVC. Optimum

Table 1.2-1. Adsorption of PCBs from Raw Sewage

ADSORBENT	% PCB ADSORBED*
Lignite Carbon	46
Polyurethane Foam	35
Amberlite XAD-2	23
Amberlite XAD-4	60
PVC	73

* Includes both Aroclors 1254 and 1260. Data are averaged over several determinations to minimize the variations in raw sewage.

retention time, and methods of continuous fresh addition and removal of spent PVC are under study.

The strong competition between organic solids and non-organic media is further emphasized in the following section on clays and humus from soils.

1.3 PCBs Adsorption on Clays and Soil Organics; Adsorbent Competition

E. S. Tucker and coworkers at Monsanto reported on studies of migration of PCBs (Aroclor 1016) through various soils as induced by percolating water. (Bulletin of Environmental Contamination and Toxicology 13 (1):86 (1975)). This was for application to landfill leaching estimates.

Their tests first led them to believe that the higher the clay content of a soil, the better its retention of PCBs.

The experimental procedure employed consisted of percolating water through a column packed with soil coated with Aroclor 1016 and then monitoring the effluent water for PCBs. The soil columns employed were approximately 3" in diameter by 12" in height and were dry packed in layers. Each soil layer being 3" thick - first uncoated soil, followed by soil coated with 2.5% (w/w) of Aroclor 1016, and finally another layer of uncoated soil. An acetone solution of Aroclor 1016 was used to coat the air dried soil, followed by removal of the acetone in a rotary evaporator.

Three different types of soils were used in this study. The characteristics of each are shown in Table 1.3-1.

The intent was to simulate the various soil types which could be encountered at different landfill sites. The soils and the procedure employed have been used to evaluate the soil mobility of agricultural chemicals.

Distilled water was fed from the reservoir at a constant pressure to each soil column. The flow rates were observed to increase, the first few days, and then decrease and level out. Apparently, after the wetting phase some channeling occurs until the soil becomes compressed in the column. This effect was most pronounced with the silty soils. The average flow rates in liters/day

TABLE 1.3-1

COMPOSITION OF SOILS USED IN STUDY

Soil	Norfolk Sandy Loam	Ray Silty Loam	Drummer Silty Clay Loam
% Sand	82.5	6.2	2.8
% Silt	11.0	83.2	55.4
% Clay	5.5	9.6	35.8
% Organic Carbon	1.0	1.0	6.0

for Norfolk Sandy Loam, Ray Silty Loam and Drummer Silty Clay were 0.26, 0.53 and 0.32, respectively.

The effluents were then quantitatively adsorbed on polyurethane columns, and then extracted and analyzed by electron capture gas chromatography.

1.3.1 PCBs Adsorption Results

PCBs adsorption results are given in Table 1.3.1-1. These results seemed to indicate that clay was the strong adsorbent for PCBs. This would have been in agreement with the work of R. Hague and co-workers (Environmental Service Technology, 8:139 (1974)), in which clay was found to have a high affinity for PCBs.

However, in later work with pure clays, the retention was not found to be as good as expected. Attention was then directed to the organic portion of the soils. They have tentatively decided that the organic fraction is more important to the adsorption of PCBs, and it can be seen from the data that the high-clay-content soil was also the high-organic-content soil.

Further investigation of some clays might be warranted. Dr. S. Pearson of Hercules, Inc., in a personal communication stated that bentonite clay was very effective in removing other pesticide wastes from water. The finely divided clay was then rapidly removed from the water with "Hercofloc".

1.4 Sphagnum Peat (Lignin-Cellulose) or an Adsorbent

The above work by Tucker, and the general finding that sewage sludge solids contain many times the amount of PCBs as that in the water phase they contain, leads to the conclusion that natural organic materials from the earth might make good adsorbents for PCBs.

Although it has not yet been tested on PCBs, there is a commercial method of continuous wastewater treatment that makes use of sphagnum peat. It is the Hussong/Couplan Water Treatment System. The peat is formed into a continuous mat on a mesh belt through which the water is sprayed. The system has shown high effectiveness in removing certain organics and metals from wastewaters.

TABLE 1.3.1-1

PCBs FOUND IN PERCOLATING WATER

Norfolk Sandy Loam		Ray Silty Loam		Drummer Silty Clay Loam	
Total Effluent Volume (ℓ)	ppb PCBs	Total Effluent Volume (ℓ)	ppb PCBs	Total Effluent Volume (ℓ)	ppb PCBs
1.3-8.1	ND	2.7-16.4	ND	1.6-9.9	ND
10.1	ND	20.7	65	12.5	ND
13.5	23	27.6	92	16.6	ND
25.5	63	51.9	153	31.4	ND
48.1	63	98.1	136	59.2	ND

ND = None detected, < 1 ppb

Capital costs for a system average about 60¢ per gallon of daily capacity. Operating costs when treating a dye house effluent were 7¢ to 14¢ per 1000 gallons.

2.0 CATALYTIC REDUCTION

In the review of PCB literature two approaches were found to modifications of chemical structure that could aid in waste control. One approach was the complete chlorination of PCBs, to give decachlorobiphenyl. The rationale here was that the completely chlorinated biphenyl would have the least solubility in water of any PCB, and thus would be much easier to adsorb and remove. However, this is in the direction of creating the most refractory PCBs also.

Another approach, presenting more favorable aspects, is the dechlorination of PCBs to give biphenyl or bicyclohexyl. Berg, et al (in the Bulletin of Environmental Contamination Toxicology 7:338 (1972)) state that PCBs can be dechlorinated quantitatively with hydrogen over platinum or palladium catalysts to give one product: bicyclohexyl.

T. Sawai of Japan, in Genshiryohu Kogyo 18(12):43-7 (1972), reported the degradation of PCBs using the cobalt 60 isotope. Gamma irradiation at a level of 10^{18} ev/gram produced chain dechlorination in an alkaline propanol solution saturated with nitrogen. Alkaline concentrations of 0.01 molar gave about 40 times the dechlorination that a neutral solution gave.

A process of reductive dechlorination, more amenable to low cost operation and commercial scaleup, is being developed by Sweeny, Saltonstall and co-workers at Envirogenics Systems Co. of El Monte, California.

2.1 Reductive Dechlorination of PCBs at Envirogenics Systems Corp.

Envirogenics, originally working in chlorinated pesticides, has developed catalyzed reduction process methods for the following compounds:

DDT
DDD
Kelthane
Perthane
Methoxychlor
Lindane

aldrin
CHLORDANE
dieldrin
endrin
heptachlor
toxaphene

Aroclor 1221
Aroclor 1242
Aroclor 1254
Aroclor 1232
Aroclor 1248
Aroclor 1260

The reductive dechlorination reaction has been run at ambient temperature and pressure, by flowing the liquid chlorinated hydrocarbon through a column containing metallic iron granules with a metallic copper coating, blended with sand. The copper exerts a catalytic action. pH is maintained at nearly neutral, since with low pH, say 2.0, the iron conversion rate to ferrous chloride goes up 10 times, but the reaction is not that much faster. That is, the effluent $FeCl_2$ content goes up to 50 ppm from 5ppm. The chlorinated hydrocarbon is converted to a hydrocarbon.

PCBs, in this process, seemed to lose chlorines stepwise, leaving unidentified halogens.

Envirogenics is now under EPA contract #68-03-2364, to develop and demonstrate at the bench-scale level (1-3 gpm), an effective, low-cost, practical process for the treatment of dilute (ppb to 1 ppm) aqueous manufacturing and processing wastes containing polychlorinated biphenyls.

Specific objectives and guidelines include:

1. Reduction of PCBs to 5 ppb or less, with levels of < 1 ppb desirable.
2. Sufficiently low projected treatment cost to be economically attractive.
3. Low expected toxicity of all effluent products, including both degraded PCBs and any added reagents.
4. Use of readily available materials, both in construction and as reagents.

The process is simply pumping the liquid to be treated through the catalytic column. Process characteristics that might be proposed for the scaled-up PCB process, based on what has been learned about the other pesticides thus far, are:

catalyst: 100 mesh metallic iron granules coated with 0.1 milliequivalents of copper per gram of iron

support: 60 to 100 mesh (approx) sand

number of beds: 4, operable in series or parallel

bed composition: 500 pounds iron catalyst, plus 3500 pounds sand flow rates: 2 to 10 gpm per square foot

pressure drop: about 10 psi

pH: Kept neutral through caustic

piping: 304 ss, with teflon tape seals

tanks: Steel with epoxy coating inside

pretreatment: Wastes are assumed to be free of undissolved solids and oils; They are fabric filtered before entering process

The expectations for PCB reductions in wastewater with a pilot plant like above, are based on small one- to two-inch diameter column lab tests with PCBs that gave reductions from 50 ppb to less than 0.1 ppb.

The capital cost of the equipment to process 100 gpm is estimated at about $65,000, plus tank storage and erection costs. Operating costs, including amortization of capital, is estimated at 72¢ per 1000 gallons of effluent.

3.0 CATALYTIC OXIDATION AND MISCELLANEOUS REACTIONS

This category of PCBs destruction includes oxidation by: air, oxygen, ozone, hydrogen peroxide and chlorine dioxide; usually assisted by catalysts or reaction sensitizers.

The PCBs are very resistant to chemical attack. Monsanto states that they are not affected by boiling sodium hydroxide, or by long contact, say 10 days, with concentrated sulfuric acid at ambient temperature. There is no apparent reaction in a bomb at 250 psi of oxygen and 140°C.

3.1 Strong Acids

Russian workers have reported nitric acid decomposition of PCBs. They used nitric acid of density = 1.4, and refluxed two PCBs, a pentachloro and a heptachloro homolog for periods ranging up to 100 hours. They found dichloro and trichloro benzoic acids from the former; and trichloro and tetrachloro benzoic acids from the latter (heptachloro). Less concentrated nitric acid would not oxidize these compounds, nor would potassium permanganate or chromic acid. However, mono-, di- and tri-chlorobiphenyls can be oxidized to the corresponding chloro-benzoic acids with chromic anhydride and acetic acid.

The less rigorous conditions can also produce a large mixture of nitrated chlorobiphenyls.

3.2 Electrochemical Oxidation

Notwithstanding these examples of oxidative resistance, J. D. Stuart and co-workers at the Dept. of Chemistry of University of Connecticut have conducted laboratory electrochemical oxidations of PCBs at ambient temperature and pressure. They oxidized PCBs with one to ten chlorine atoms, using very high anodic potentials in a dry methyl cyanide solvent. They believed that a series of reactions occurred, starting with hydrolysis from traces of water present, followed by oxidation.

A number of other catalytic oxidation investigations of refractory organics are being conducted throughout the U.S., some being sponsored by branches of EPA. Although PCBs have not been tested in these cases yet, the methods have sufficient power and flexibility to predict that PCBs could be destroyed. In addition, these are methods that have the potential of zero discharge since they have converted refractory organics to CO_2 and water.

3.3 Catalytic Ozonation and Ultrasound Decomposition of Organics

Prof. Gerald Smith and J. W. Chew of Southern Illinois University presented results of catalytic ozonations of non-PCB organics in aqueous systems at the 68th annual AIChE Meeting in November 1975. They tried catalyst with oxygen, and ozonation without catalyst, and neither method had the effectiveness of catalytic ozonation. An Fe_2O_3 catalyst was used, and phenol and ethyl acetoacetate were used as model compounds in water. With a liquid retention time in their flow reactor system of 25 minutes, and a gas flow of 0.1 liter/minute of 30 mg/liter concentration of ozone, % TOC removed was 95% for an initial TOC of 100 mg/l and about 85% for an initial TOC of 400 mg/l. The packed reactor had the aqueous solution flowing down, and the ozone flowing up.

In experiments comparing the effectiveness against refractory organics of ozone plus Raney nickel and ozone plus ultrasound, Prof. Smith found that the reactions were similar. Also, he found that ultrasound and oxygen have similar reactions. It appeared, however, that all of these effects could not be added together to get greater oxidative reaction. For example, adding ultrasound to an ozone catalytic reaction did not materially change the reactivity of just ozone and the catalyst with the organics. Ultrasound was applied at 800 KHz, and 4 to 5 watts/sq. cm. He also found that at these ambient temperature and pressure conditions, although phenol disappeared rapidly, other organics formed were oxygenated aromatics rather than those formed from rupture of the aromatic ring.

3.4 Wet Catalytic Oxidation of PCBs

Dr. L. W. Ross at Denver Research Institute has studied the wet catalytic oxidation of strong wastewaters having COD values of 3,000 to 15,000. Tests showed that $Fe_2 (SO_4)_3$ - $Cu SO_4$ - H_2O_2 at pH 5.0 and Fenton catalyst at pH 2.5 gave COD reductions of 95.4% and 96.0% respectively after 2 hours at 400°F. Platinum oxide as a solid catalyst also gave good results. Most of the organics were cellubiosics.

3.5 Wet Catalytic Oxidation and Catalyst Durability

Prof. J. F. Katzer and co-workers at University of Delaware have been studying the elevated pressure and elevated temperature catalytic air-oxidation of refractory organics. They are currently being supported by EPA in a study of the durability of catalysts in wastewater environments. In a paper soon to be published in the Journal of the Water Pollution Control Federation, Katzer reports on studies of the complete oxidation of phenol to CO_2 and water in an aqueous medium using a supported copper oxide catalyst. Rapid degradation rates were found, and the rate data were used to run preliminary design and costs for commercial-sized waste treatment plants. His conclusion is that catalytic oxidation of wastewaters is cost competitive with other physical chemical treatment techniques.

Katzer found that pressures of 10 to 20 atm, and temperatures of 100 to 200°C were required to get adequate reaction rates and give up to 99% destruction of organics to CO_2 and water. It was found that ambient temperature and pressure generally caused more adsorption on a variety of catalysts, than any reaction.

3.6 Dye-Sensitized Visible Light Photo-Oxidation of Organics

Prof. R. L. Sanks and co-workers at the Civil Engineering Dept. of Montana State University are working on the dye-sensitized, aerobic, photo-oxidation of refractory organics. They were able to rapidly break apart the benzene ring of cresol using dyes like methylene blue or bengal rose. The key to the process is that in the presence of sunlight and air, methylene blue can produce singlet oxygen from the O_2 in air. There are two forms of this singlet oxygen, with a half life of only a millisecond, but with the ability to easily shatter benzene rings. Prof. Sanks visualizes a process whereby a lagoon containing wastewater with refractory organics, could have the dye molecules attached to a long chain alkyl or a floc of some kind to keep it at the surface. The sun would provide the photolysis, and little dye would be consumed as it is a catalyst in the reaction. Such a process, if it can be developed, suggests a route to a very low cost method of obtaining zero discharge, and water recycle systems.

3.7 Chlorine Dioxide Oxidation

International Dioxide, Inc. of New York City is offering a stabilized chlorine dioxide. It is being used by municipalities for taste and odor control of water. It is used as an adjunct to chlorination and can decompose chloramines. It oxidizes and destroys phenol and does not chlorinate. Unstabilized ClO_2 is a dangerous explosive, thus this stabilization offers a very powerful oxidizing agent for potential degradation of organics.

4.0 DESTRUCTION OF PCBs BY MICROORGANISMS

"The Chemistry of PCBs", by Hutzinger reports only two pure cultures of micro organisms that had shown metabolic activity on individual chlorobiphenyls up until the end of 1973. One culture, *Rhizopus japonicus* only converted the mono- or dichlorobiphenyls to chlorohydroxy biphenyls or possibly multi-hydroxy-biphenyls.

More promising results were obtained with two species of Achromobacter, isolated from sewage effluent. Under aerobic conditions, 4-Chlorobiphenyl was converted to 4-chlorobenzoic acid. It appeared that the organism was able to attack the non-chlorinated benzene ring. Most of these degradations take quite a number of hours to occur. More recently, up to pentachloro-biphenyls have been oxidized by Achromo bacter. Monsanto was able to demonstrate a significant reduction in the one, two and three chlorobiphenyls of Aroclor 1242 after 72 hours of treatment with activated sludge. The higher chlorinated homologs did not seem to be affected.

The degradation of PCBs by microbial action from sludges and pure cultures seemed to give results similar to animal metabolism studies. The lower chlorinated species, again up to about the trichloro homolog were decomposed to phenols, catechols and related compounds.

The importance of oxidative conditions was demonstrated in tests with silage containing PCBs. After several months of storage of Aroclor 1242 with silage that had undergone fermentation reactions under anerobic conditions, no change in any of the PCBs had taken place.

The use of DDT degradation as a model for PCB degradation conditions may not be too helpful. Results of a study by Johnsen (PCB Newsletter, January 1973) showed that di- to hexachloro biphenyls were incubated for one month with soil and soil containing cattle manure. No indication of PCB metabolism was found. Under these conditions; p,p' DDT degrades almost completely.

It has also been found that biphenyl itself is more easily degraded or hydroxylated, than any of the chlorinated biphenyls.

5.0 REVERSE OSMOSIS AND ULTRAFILTRATION

No tests for PCBs removal by these technologies were found in our survey.

Generally, these methods have found most success in removing dissolved salts from water. However, DuPont reports in a private communication that they have achieved 99% removal (rejection) of organics in water at the 1000 to 2000 ppm level. They have developed the hollow fiber permeator system, and the fibers are aromatic polyamides. The system is reported to work well on streams with molecular weights greater than 100. This would predict good success with the PCBs, all of which have molecular weights about 2 to 4 times that high.

U.O.P.'s Fluid Systems Division reports in a private communication, that based on their success with wound experimental polyamide membranes operating on chlorinated hydrocarbons in water, they would predict a 95% to 97% removal of PCBs at the 50 ppb level in water. They point out however, that the reject water stream with concentrated PCBs would contain 10% to 20% of the original volume of wastewater. A certain amount of recycle could be built into the system to reduce the generation of concentrated wastewater. R.O. units require no suspended solids in the feed wastewater. They can operate for 6 months to one year before any maintenance for cleaning is required.

Dr. W. L. Short of the Chemical Engineering Dept. of the University of Mass. reports in a private communication that ultrafiltration has achieved 10% rejections of phenols and chlorinated phenols. He believes that rejection of a given compound can be improved by attaching some of that compound, or a similar material, to the membrane to act as a sort of electronic barrier.

APPENDIX E

Energy Requirement for Various Treatment Options

The attached Tables 1 through 6 present the estimated annual fuel oil requirement in therms (100,000 BTUs) and power requirements in kilowatt-hours for the various treatment options included in the Task II report. This information is provided in order to facilitate the assessment of the energy impact of the various levels of effluent treatment.

The estimated total PCB user industries', capacitor and transformer industries' energy requirements were facilitated by preparing energy requirements for each plant site visited during the course of these studies and then apportioning to the total industry category on the basis of the percentage of the total PCB industry represented by the visited plants.

The capacitor plants visited are Plants 100, 101, 102, 104, 105 and 106 which represent 50 percent of the PCB user capacitor industry. Transformer plants visited are Plants 103 and 114 and they represent 26 percent of PCB user transformer industry.

TABLE 1

Base Case (No Wastewater Treatment)
Estimated Annual Energy Requirement for
The Incineration of Liquid and Solids Wastes

PLANT NO.	100	101	102	103	104	105	106	114
Fuel Oil Requirement, Therms	5300	1800	2900	3100	7300	14,500	1800	2800

Estimated PCB User Industry Fuel Oil Requirement, Therms	100,000

TABLE 2

Estimated Annual Energy Requirements for Treatment of All Flows and Discharging to Receiving Stream with Carbon Final Treatment[1]

PLANT NO.	100	101	102	103	104	105	106	114
Power Requirement, million KW hr	1.25	0.14	1.13	1.75	1.60	1.13	0.83	0.20
Fuel Requirement,[2] Therms	5300	1800	2900	1100	7300	14,500	1800	2800

Estimated PCB User Industry Power Requirement, million Kw-hr 20
Estimated PCB User Industry Fuel Oil Required, Therms 100,000

Notes: Costs for this treatment option are presented in Section VII, Table 7.3.5-1, page 210.

Fuel requirement is same as the base case.

TABLE 3

Estimated Annual Energy Requirements for Recirculation and Cooling of Non-Contact Cooling Water and Treatment of All Other Flows Using Carbon as Final Treatment[1]

PLANT NO.	100	101	102	103	104	105	106	114
Power Requirement, million Kw hrs	1.80	0.14	1.30	4.70	2.30	1.60	1.10	0.24
Power Requirement[2] neglecting rainwater million Kw hrs	1.70	0.10	0.72	4.20	2.10	1.40	0.87	0.21
Fuel Requirement,[3] Therms	5300	1800	2900	3100	7300	14,500	1800	2800

Estimated PCBs User Industry Power Requirement, million Kw-hr 40
Estimated PCBs User Industry Fuel Oil Requirement, million therms 30

Notes: [1] Costs for this treatment option are presented in Section VII, Table 3.3.3-2, page 211.

[2] This information is included for purposes of determining the rainwater contribution to the power requirement.

[3] Fuel requirement same as the base case.

TABLE 4

Estimated Annual Energy Requirements for Zero Discharge (Carbon Treatment of Non-Contact Cooling Water)[1]

PLANT NO.	100	101	102	103	104	105	106	114
Power Requirement, million Kw hr	1.40	0.11	0.63	3.30	1.70	1.10	0.74	0.16
Fuel for incineration,[2] million therms	0.925	1.841	24.903	12.083	2.207	4.415	7.801	0.923

Estimated PCBs User Industry Power Requirement, million Kw-hr	28
Estimated PCBs User Industry Fuel Oil Requirement, million therms	148

Notes: [1] Costs for this treatment option are presented in Section VII, Table 1.3.4.5-1, page 219.

[2] Includes the fuel requirement for solid and liquid PCBs waste incineration (base case fuel requirement).

TABLE 5

Estimated Annual Energy Requirements for Zero Discharge
(Segregation and Recycle of Non-Contact Cooling Water)

PLANT NO.	100	101	102	103	104	105	106	114
Power Requirement, million Kw hr	1.80	0.12	1.10	4.50	2.90	1.50	1.00	0.22
Fuel Oil Requirement, million therms	0.925	1.841	24.903	12.003	2.207	4.415	5.801	0.921

Estimated PCBs User Industry Power Requirement, million Kw-hr	10
Estimated PCBs User Industry Fuel Oil Requirement, million therms	148

Notes: Costs for this treatment option are presented in Section VII, Table 3.3.4.5-2, page 220.

Includes the fuel requirement for solid and liquid PCBs waste incineration (base case fuel requirement).

TABLE [illegible]

Estimated Annual Energy Requirements for Zero Discharge (Segregation and Recycle of Non-Contact Cooling Water) Excluding Rainwater Runoff[1]

PLANT NO.	100	101	102	103	104	105	106	[illegible]
Power Requirement million kw hr	[illegible]	0.12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fuel Oil Requirement, therms	[illegible]	1800	[illegible]	[illegible]	7500	[illegible]	[illegible]	[illegible]

Estimated PCBs User Industry Power Requirement, million kw-hr [illegible]
Estimated PCBs User Industry Fuel Oil Requirement, therms [illegible]

Notes: [1] Costs for this treatment option are presented in Section [illegible], Table 3.3.4.5-3, page 211.

[2] Same as the base case.